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## Validation Test Report for the Automated Optical Processing System (AOPS) Version 4.8

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14. ABSTRACT  This document describes the testing and evaluation of the Automated Optical Processing System (AOPS) version 4.8 for the Visible Infrared Imager Radiometer Suite (VIIRS) sensor. AOPS enables exploitation of multiple space-borne ocean color satellite sensors to provide optical conditions for operational Navy products supporting mine Warfare (MIW), Naval Special Warfare (NSW), expeditionary warfare (EXW), and antisubmarine warfare (ASW). Ocean optical products are used to predict the impact of the environment on diver operations, communications, mine detection, and target detection. As part of this evaluation, comparisons are made with existing operational satellite products from MOSIA-Aqua, in situ data from ocean cruises and comparison with the Aerosol Robotic Network-Ocean Color (AERONET-OC) SeaPrism sensors. These comparisons show that VIIRS generates high quality ocean color products and should provide a continued data stream to support operational products.					
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# Validation Test Report for the Automated Optical Processing System (AOPS) Version 4.8

## 1 Introduction

Work under the *Preparing Tactical Ocean Optical Products from Future Polar-Orbiting Sensors* project enables exploitation of the Visible Infrared Imager Radiometer Suite (VIIRS) and similar ocean color sensors to provide navy products for operational use. Work completed was in response to the Navy's need to exploit all available remote sensing technologies<sup>1</sup> as part of a larger effort to provide a continuous operational picture of environmental conditions of the battlespace.

This Validation Test Report (VTR) provides the technical bases to transition the Automated Optical Processing System (AOPS) version 4.8 to the NP3 Ocean Optics branch of the Naval Oceanographic Office (NAVOCEANO). AOPS is a fundamental capability allowing NAVOCEANO to produce operational ocean optical conditions from satellite imagery. AOPS is the current tool that NAVOCEANO uses to provide operational products to fleet operators engaged in Naval Special Warfare (NSW), Mine Warfare (MIW), Expeditionary Warfare (EXW), and Anti-Submarine Warfare (ASW). The same products are also used in real time to support analysis of ocean models by oceanographers on the NAVOCEANO watch floor.

The project was divided into four task areas, where AOPS is identified as the transitioning element of the project. As the transition, AOPS v4.8 provides tools and algorithms to process data from environmental remote sensing satellites in accordance with the Meteorology and Oceanography (METOC) Space Satellite readiness plan and enables rapid dissemination of final products via NAVOCEANO's web portal and other avenues compliant with internal policies. The AOPS collection of programs allows scientists to generate co-registered image databases of geophysical parameters derived from remotely sensed data. To accomplish this, AOPS uses the techniques of *extension* and *automation*.

*Extension* is the use of small programs, each designed for a specific task, and a shell to 'glue' them together. The idea is similar to the UNIX operating system and its many programs like `cat`, `tr`, `basename`, etc. and allows the user to augment the system with their own features and programs.

*Automation* is the technique of operating a system without human effort or decision. For AOPS, this is achieved by setting up a directory structure and using scripts to monitor the directories for new input data -- as new data is made available to the system, it is processed without user intervention.

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<sup>1</sup> In light of the aging MODIS satellites and current status of the DWSS program, the Joint Polar Satellite System (JPSS) satellite and other foreign sensors are expected to be the primary sources of DOD METOC data for the next 20 years. Naval operations will rely on the integration of these sensors into current operational processing to provide continuity of legacy products and spatial coverage of current operational areas.

AOPS does not contain GUIs or visualization programs; therefore all user input *must* be provided to the program upon *start*.

## 2 System Description

AOPS is a collection of UNIX programs and shell scripts that enables automated generation of map-projected image data bases of satellite derived products from streaming raw satellite data. Individual scenes are sequentially processed from the raw digital counts (Level-1) using standard parameters to a radiometrically and geometrically corrected (Level-3) product within several minutes. AOPS further processes the data into a variety of temporal composites called mosaics (Level-4). These products are stored in the Hierarchical Data Format (HDF) with specific attributes. Additionally, it automatically generates quick-look “browse” images in JPEG format. Historically, AOPS was capable of processing data from: Medium Resolution Imaging Spectrometer (MERIS), Moderate Resolution Imaging Spectrometers (MODIS on Aqua), and Sea-viewing Wide Field-of-view Sensor (SeaWiFS)<sup>2</sup>. This VTR documents the new capability in AOPS to produce operational products from the Joint Polar Orbiting System (JPSS) – Suomi National Polar-orbiting Partnership (NPP) with the VIIRS sensor package and includes algorithm improvements requested by NAVOCEANO.

AOPS uses a simple monitoring technique. The main driver regularly polls a specified input directory for incoming data and for each file found, executes what are known as *areas* scripts on the file in a working directory. The *areas* scripts do the actual construction of the desired results (i.e. the data bases). After each *areas* script has been run on the file, it is moved to an output directory. This method uses the directory as the queuing system for data to be processed.

The 4.8 version represents the most recent processing algorithms employed at the Naval Research Laboratory as of 26 NOV 2012 for current operational sensors. The system has been developed on CentOS 5.7 (x86, x86\_64) – equivalent to RHEL v5.

The primary upgrade in AOPS v4.8 provides the ability to produce operational products using the new visible sensor, NPP- VIIRS aboard the JPSS satellite. NPP, *the heritage NPOESS satellite*, was launched on Oct 28, 2011 and has since been undergoing sensor cal/val by National Oceanographic and Atmospheric Administration (NOAA), National Aeronautic and Space Administration (NASA) and Naval Research Laboratory (NRL). VIIRS has 7 visible and near infrared (NIR) ocean channels: M1-M7 (412 nm, 443 nm, 488 nm, 551nm, 670 nm, 765 nm, and 865 nm) that are used for ocean color and atmospheric products. Sensor characterization is critical to the end navy products because the ocean color signal represents only 10 percent of the total radiance signal at the top of the atmosphere (TOA). Errors in sensor calibration, out of spectral band response issues, polarization, and atmospheric correction must be accounted for so that operational navy products can be accurate and provide consistency with existing ocean color products.

Navy products from AOPS include: diver visibility, laser penetration depth, chlorophyll concentration, and inherent optical products<sup>3</sup>. In addition to providing a depiction of the environment, the products can

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<sup>2</sup> MERIS and SeaWiFS have been removed as both satellites have retired.

<sup>3</sup> These specific navy optical products are computed based on the “normalized water leaving radiance” (nLw) or the water spectrometry. The ability of the sensor to retrieve the navy products is based on the accuracy of the nLw retrieval. The accuracy of the algorithms for going from nLw to optical properties was evaluated in prior VTR. We are using similar algorithms to existing satellites and only changing the spectral response of the VIIRS sensor.

be used for validation of or assimilation into ocean forecast models. Ocean optical products are used to predict the impact of the environment on navy systems used in communication, mine detection and target detection.

The VTR for AOPS v4.8 describes the testing and data comparisons necessary to demonstrate that the products derived from the VIIRS sensor can be used for navy operations and should be integrated into NAVOCEANO operations to support the fleet. We will demonstrate the operation capability by comparison with 1) existing operational satellite products from MODIS, 2) comparison with *in situ* data from ocean cruise and 3) comparison with the Aerosol Robotic Network- Ocean Color (AERONET-OC) SeaPrism sensors.

Beyond addition of the VIIRS processing capability, AOPS v4.8 includes the following upgrades:

1. Upgrade of the Quasi-Analytical Algorithm (QAA)(*See Appendix: Figure A 1 - Figure A 4*)
2. Upgrade of the calibration for MODIS processing (MCST desert based calibrations (*See Figure 3, Figure 4*))
3. Upgrades to n2gen processing that improve spectral accuracy (*See Figure 19*)
4. APS v4.8 incorporates SEADAS 6.4 and 7.0b.

## 2.1 System Requirements

AOPS runs in the RHEL-Linux environment. Users should be familiar with UNIX; BASH shell programming; and remote sensing, particularly regarding computer processing of satellite data. The system memory and storage requirements are difficult to gauge. The amount of memory needed is dependent upon the amount and type of satellite data you wish to process; the larger the area, the larger the memory requirement. For example, the entire Atlantic Ocean will require more processing power than the Mississippi Bight. In addition, the type of data being processed will determine how robust the system should be. Data storage requirements are a function of the temporal and spatial needs of both the NAVOCEANO system operators and the data consumers. A technical description for how to use AOPS that would enable identification of memory and disk space requirements is provided in the AOPS Users Guide v4.8, 2012.

### 2.1.1 Data Input

Currently AOPS supports VIIRS inputs provided by the Air Force Weather Agency (AFWA) stream delivered to NAVOCEANO. A redundant data stream is available through NOAA's Comprehensive Large Array-data Stewardship System (CLASS) and Government Resource for Algorithm Verification, Independent Testing and Evaluation (GRAVITE) systems. At the time of this writing the three data sources are identical therefore after establishing data subscriptions, processing is transparent.

The AOPS format is based on the Scientific Data Sets interface in version 4 of the Hierarchical Data Format (HDF4). No other interface or objects are used or allowed in a valid APS file.



Within the Scientific Data Sets subset, a valid APS file is limited to an array of no more than three dimensions one of which may be UNLIMITED. All standard number types (INT8, UINT8, INT16, UINT16, INT32, UINT32, FLOAT32, FLOAT64, and CHAR8) may be used.

None of the pre-defined attributes using such API's as `SDgetdatastrs()`, for example, are used. The APS format supports both file and data set attributes. The APS format has several required file and data set attributes that must exist with each file or data set, respectively.

There is no limit to the number of data sets other than those imposed by the HDF4 library. However, there are some limits placed on the names of general data set names.

The APS IO library contains routines for accessing all objects from the APS file. Use of this library is strongly encouraged as the underlying file structure may change. The AOPS User's Guide v4.8, 2012 describes the file format structure as well as the use of the library.

## 2.1.2 AOPS Output

### 2.1.2.1 Level 3 Regional Data Products

AOPS generates radiometrically and geometrically corrected (Level-3) products within several minutes. There are a *variable* number of data sets in an AOPS Level-3 Regional Data Product file. The *meta data sets* are standard, providing geographical coverage and data quality information. The *product data sets* contain the actual geophysical products and vary in number. A long descriptive name is used to facilitate use of the *product data sets*, and in some cases, the algorithm used is also provided in the name. Examples are "Remote Sensing Reflectance at 443 nm" and "Chlorophyll Concentration, OC4 Algorithm". File attributes are associated with all products in the HDF file. The attributes are divided into several groups and a detailed discussion can be found in the AOPS Users Guide v4.8, 2012.

### 2.1.2.2 Level-4 Regional Data Products

AOPS also generates several different temporal composites (Level-4). The Level-4 Regional Data Product File contains atmospherically corrected geophysical products in a standard map projection for a specific region of interest derived from one of several different satellites (AVHRR, MERIS, MODIS, "High-Res" MODIS, OCM, SeaWiFS, VIIRS). A Level-4 Regional Data Product may be stored in one of several formats. The default is stored using HDF developed by the National Center for Supercomputer Applications (NCSA) at U. of Illinois Urbana-Champaign (version 4.2.8). Additional output file types that are supported include: version 5 of the HDF format (using HDF5 v1.8.6) and the netCDF v4. A technical description can be found in the AOPS Users Guide v4.8, 2012.

## 3 Validation Test descriptions

Traditional *ground truthing* is one of two approaches to evaluate the VIIRS ocean color products. The technique is enhanced by using procedures that follows the NASA OBPG on-orbit vicarious calibration

approach<sup>4</sup>. By using short term (*< 6 months*) time series measurements from the Marine Optical Buoy (MOBY) and other *in situ* data collection assets such as the AERONET-OC robotic network, VIIRS products are monitored by a match-up procedure that will be described later in this document.

The second approach for evaluating NPP ocean color products is direct comparison with existing satellite products such as MODIS. This cross-platform technique will rapidly provide consistent data sets from which global metrics of the NPP products can be established. Cross-platform calibration will allow validation of products in critical coastal regions where *in situ* data is not available.

### MOBY

MOBY, a radiometric buoy located in the waters off Lanai, Hawaii, in 1200 m of water, is the primary ocean observatory for vicarious calibration of satellite ocean color sensors. Since late 1996, it has been the primary basis for the on-orbit vicarious calibration of the USA Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Japanese Ocean Color and Temperature Sensor (OCTS) and Global Imager (GLI), the French Polarization Detection Environmental Radiometer (POLDER), the USA Moderate Resolution Imaging Spectrometers (MODIS, Terra and Aqua), and the European Medium Resolution Imaging Spectrometer (MERIS). The MOBY site vicarious calibration of these sensors supports the international effort to develop a global, multi-year time series of consistently calibrated ocean color data products. Current uncertainty for MOBY is approximately 5% for MODIS channels 8 through 12 and 12.5% for channel 13 due to the large shadowing correction (Brown et al. 2007). Advanced processing techniques can drop the uncertainty to less than 3% for MODIS channels 8 to 12, and 3.3% for channel 13 (Melin et al., 2007, Zibordi et al., 2009, Zibordi 2012 *personal communication*).

### AERONET-OC

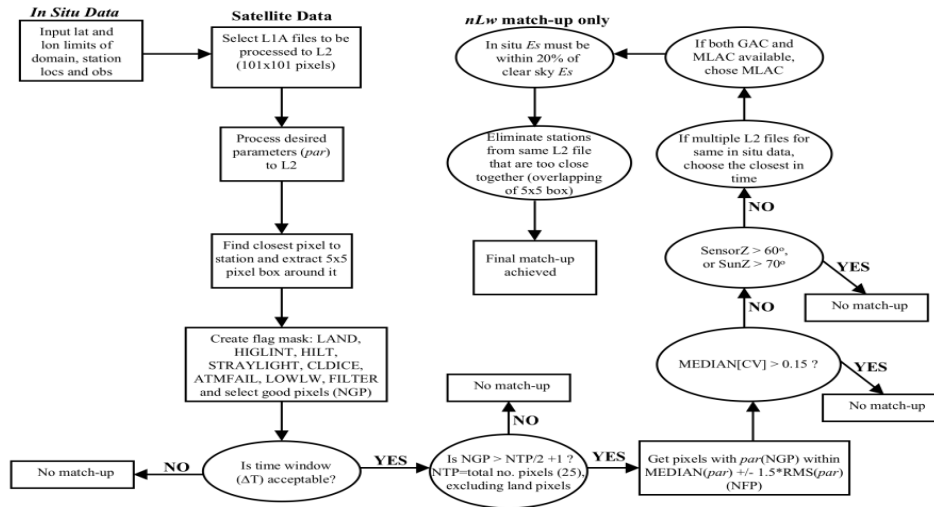
AERONET-OC is a sub-network of the Aerosol Robotic Network (AERONET), using modified sun-photometers to support ocean color validation activities with standardized measurements of normalized water leaving radiance and of aerosol optical properties. Autonomous radiometers are operated on fixed platforms in coastal regions. Significant attention is given to implementing identical systems and protocols. The rationale for the AERONET-OC is to assess the accuracies of coastal nLw from current ocean color sensors. Since 2006 the AERONET-OC network has increased in both number of sites and individual users, including several Space Agencies and the VIIRS Team. An estimate of the overall uncertainty budget in AERONET-OC Lwn (Level 2) has shown values typically below 5% at the blue and green center wavelengths (D'Alimonte and Zibordi, 2006; D'Alimonte et al. 2008; Zibordi et al. 2009). Uncertainties around 8% have been estimated for the red center wavelengths.

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<sup>4</sup> Unmodified, the technique requires several years of coincident satellite and *in situ* (i.e., MOBY) data before sufficient matchups produce a valid vicarious calibration.

## Calibration and Validation Process

The current procedure for ocean color cal/val following the NASA Ocean Biology Processing Group (OBPG) vicarious calibration approach requires several years of coincident satellite and high quality *in situ* data (i.e., MOBY<sup>5</sup>, global cruise data) before sufficient matchups produce a valid vicarious calibration<sup>6</sup> (Figure 1). By allowing flexibility of the screening process and utilizing the coastal AERONET-OC sites as data with some calibration value, in spite of its higher variability, practicable vicarious gains can be generated and subsequently fined-tuned as additional data becomes available.



**Figure 1 Match-up procedure for comparing *in situ* and satellite data employed by NRL is similar to that used by NASA OBPG.**

The Satellite Validation Navy Tool (SAVANT) provides NRL the semi-automated capability for performing flexible match-up analysis following the NASA OBPG procedures. *In situ* (Level 1.5) and corresponding 25km<sup>2</sup> box of satellite data (Level 3) are accessed by position (lat, long) through SAVANT.

<sup>5</sup> MOBY data is used for vicarious calibration (gain calculations) and oceanographic cruise data is used for validation (typically 3x3 box)

<sup>6</sup> Over 9-years, MOBY provided about 1450 contemporaneous match ups for SeaWiFS and only 150 match-ups passed the stringent screening processes for long-term vicarious calibration (*approximately 17 per year*).

- The time window is set to define coincident as  $\pm 3$  hours.
- *In situ* data is screened as follows:
  - exclude wind speeds  $> 8$  m/s
  - set a maximum Aerosol Optical Thickness (AOT) = 0.2
  - set the minimum nLw value = 0
  - set the maximum nLw value = 3
- Satellite data is screened as follows:
  - set the maximum Coefficient of Variance = 0.30
  - set the minimum percent valid pixel requirement to 50
  - set the satellite box size = 25km (5x5)
  - set the satellite zenith angle minimum = 0 and maximum = 56
  - set the solar zenith angle minimum = 0 and maximum = 70
  - set the satellite azimuthal angle minimum = -180 and maximum = 180
  - set the solar azimuthal angle minimum = -180 and maximum = 180
- The Level 2 quality flags are applied to satellite data to exclude scenes of : Atmospheric Failure, High Light, Cloud/Ice, Low water-leaving radiance, land, high satellite zenith angle, high solar zenith angle, navigation failure, high glint, stray light, max AER iteration, high polarization, and moderate sun glint.

By employing the above filtering and processing techniques, *in situ* data is directly compared to the satellite data to track satellite performance over time. Coincident collections are also matched-up to determine to assess satellite bias. The combined temporal monitoring and bias determinations enable the long and short term assessments of satellite stability and define the uncertainty of the ocean color products.

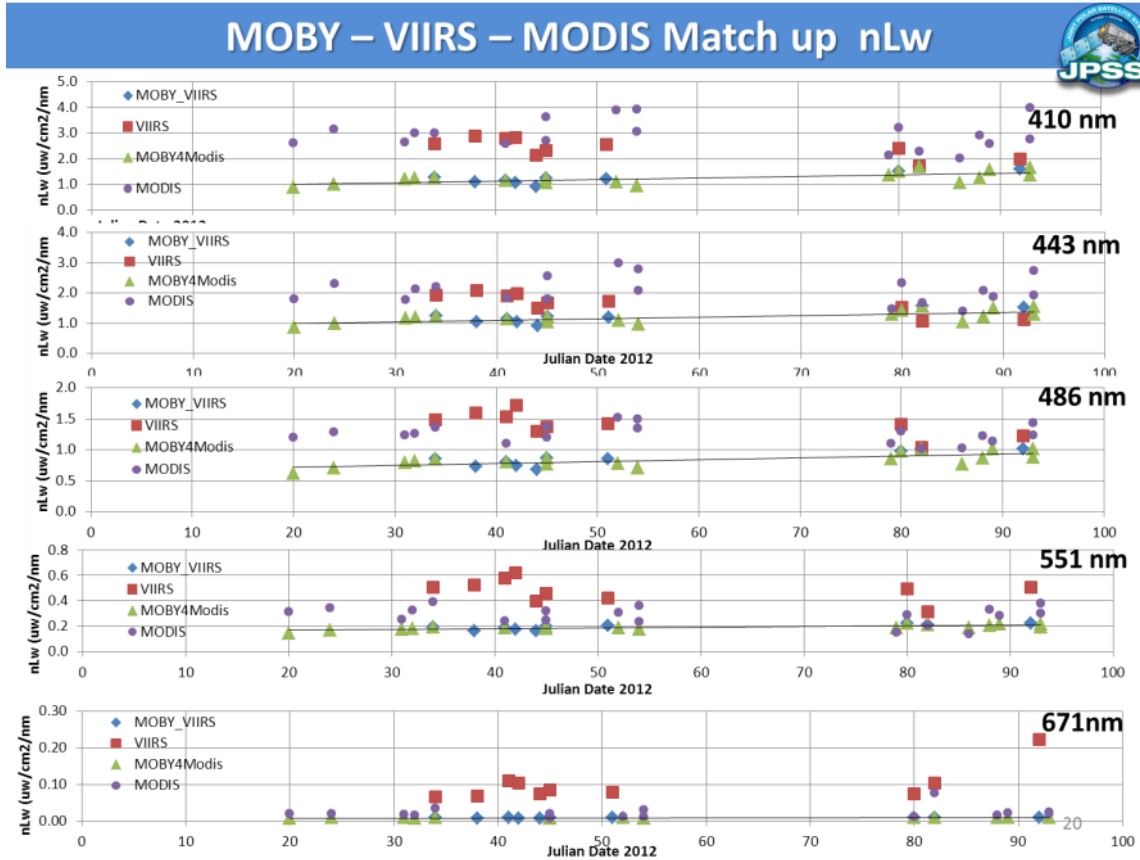
The technical details of development and implementation are provided in the Space and Naval Warfare Systems Command (SPAWAR) FY2011 and FY2012 Monthly Progress Reports, Bailey et al, 2008, and Franz et al 2007.

Calibration and validation for VIIRS should be completed in the open ocean (mesoscale) prior to the coastal waters. For cal/val efforts specific to ocean color products in coastal waters, scientists need to resolve variability issues on the spatial-temporal scale seen in coastal waters (i.e., shelf and slope waters have events driven by winds and tidal forces). Coastal regions are optically and atmospherically complex, and collected *in situ* data have large errors (both in measurement and sampling), making it difficult to relate *in situ* point measurements to satellite pixels on the order of 0.1 to 1 sq. km. New match-up procedures, and statistical and numerical modeling techniques, will need to be researched to deal with the variability in the *in situ* data when compared to the satellite data. In addition, new metrics for coastal zone performance assessment will need to be developed to evaluate products and algorithms.

### 3.1 MOBY, AERONET-OC and *In situ* matchups

#### 3.1.1 MOBY Site –Pacific Ocean, Hawaii

When considering calibration and validation activities it is important to take into account the physical dynamics of the coastal ocean versus the stability of the ocean gyres. Functionally, the effects of geometric and natural variability can be minimized by assessing the nLw matchups at the MOBY site. Figure 2 shows a time series of the match-ups between the VIIRS, MODIS and MOBY (*in situ*) data. The MOBY data has been convolved to match the spectral responses of VIIRS and MODIS. The MOBY\_VIIRS data (blue) is the time series of MOBY data to be analyzed with respect to the VIIRS data (red). The MOBY4Modis data (green) is for comparison with the MODIS data (purple). The data is presented for five wavelengths in the visible spectrum. At 410 nm and 443 nm, both MODIS and VIIRS satellite retrievals are higher than expected (*in situ*) with the VIIRS tending to outperform MODIS in this examination. At longer wavelengths, the retrievals improve with time and qualitatively at this time; the MODIS calibration for these wavelengths is performing better than VIIRS. *Recall coincident MODIS collection meets the temporal requirement for high quality data collection needed to perform the vicarious calibration technique.* As the calibration for VIIRS matures and implementation of a time independent f-LUT calibration is realized the VIIRS performance will show continued improvement over time.



**Figure 2 – This figure shows a time series of the match-ups between the VIIRS, MODIS and MOBY (*in situ*) data. The MOBY data has been convolved to match the spectral responses of VIIRS and MODIS. The MOBY\_VIIRS data (blue) is the time series of MOBY data to be analyzed with respect to the VIIRS data (red). The MOBY4Modis data (green) is for comparison with the MODIS data (purple). The data is presented for five wavelengths in the visible spectrum. At 410 nm and 443 nm, both MODIS and VIIRS satellite retrievals are higher than expected (*in situ*) with the VIIRS tending to outperform MODIS in this examination. At longer wavelengths, the retrievals improve in time and qualitatively the MODIS calibration at these wavelengths is performing better than VIIRS. As the calibration for VIIRS matures and implementation of the ‘actual f-LUT’ is realized the VIIRS performance is expected to improve.**

### 3.1.2 AERONET – OC: Venice, Italy – AAOT

The AERONET- OC is a specialized network of SeaPrism instruments (*measuring ocean color*) coupled with the AERONET network. The network, managed by NASA, consists of 12 sites with the AERONET-OC capability located on ridge platforms. They collect both aerosol and water leaving radiance daily in 20 minute increments and report in near-real time. These are part of an international effort and instruments are calibrated yearly and maintained by various universities and agencies. The Navy has one AERONET-OC operating in the turbid coastal waters of the Gulf of Mexico. Strict criteria exist for data collection, protocols and processing to calculate the nLw for use in satellite product calibration and validation (Zibordi et al. 2009). To use the AERONET-OC data for near real time cal/val efforts, the NRL process utilizes an intermediate product known as Level 1.5 data.

All AERONET products are classified at 3 different quality assurance levels (QA):

- Level 1.0 - Real Time Data (data are unscreened and may not have final calibration applied)
- Level 1.5 - Real Time Cloud Screened data
- Level 2 - once the Level 1.5 data are manually inspected, they may be upgraded to Level 2 (Quality assured). Level 2 data may be reprocessed to implement new parameters (e.g., calibration).<sup>7</sup>

While the Level 1.5 data is not quality assured, long term monitoring of the Level 1.5 data allows its use to establish practicable offsets and intercomparisons. *Issues that arise with the AERONET-OC data stand out when analyzed on annual time scales.*

### Venice Results

The data collected at the Venice AERONET-OC site (AAOT) are shown in time series plots below. The data shows the nLw for each sensor over time by wavelength. Data prior to Julian Day 111 is excluded due to a fundamental change in the calibration methodology.

Figure 3 shows the time series of data available at the 412 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data between Julian Day 111 and 211 for MODIS were produced using MODIS ver 5 processing. The obvious improvements seen in MODIS data beyond Julian Day 211 utilized the MODIS ver 6 processing which includes the updated desert calibration for the 412 nm and 443 nm channels. With the exception of the ver 5 MODIS data, much of the data show the satellites are within the range of the “truth” established by the SeaPrism ( $0.3 - 1.1 \text{ W m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$ )

Figure 4 shows the time series of data available at the 443 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data between day 111 and 211 for MODIS are produced using ver 5 processing. MODIS data beyond Julian Day 211 was processed with the updated MODIS ver 6 processing. Generally the VIIRS data seems reasonable with some high and low outliers which could be due to the highly variable optical conditions known to occur in coastal waters, such as advection, biological patchiness, multiple scattering effects. The 410 and 443 wavelengths are subject to the greatest variability of water composition (colored dissolved organic matter, CDOM; suspended particulate matter, SPM; and biologics).

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<sup>7</sup> The quality assurance scheme applied to data from current AERONET-OC sites shows error rates ranging from 5% to 17% of the total measurements due to deployment restrictions, instrument performance errors, data transmission errors, and environmental factors such as cloudiness and wave perturbations (Zibordi et al. 2009).

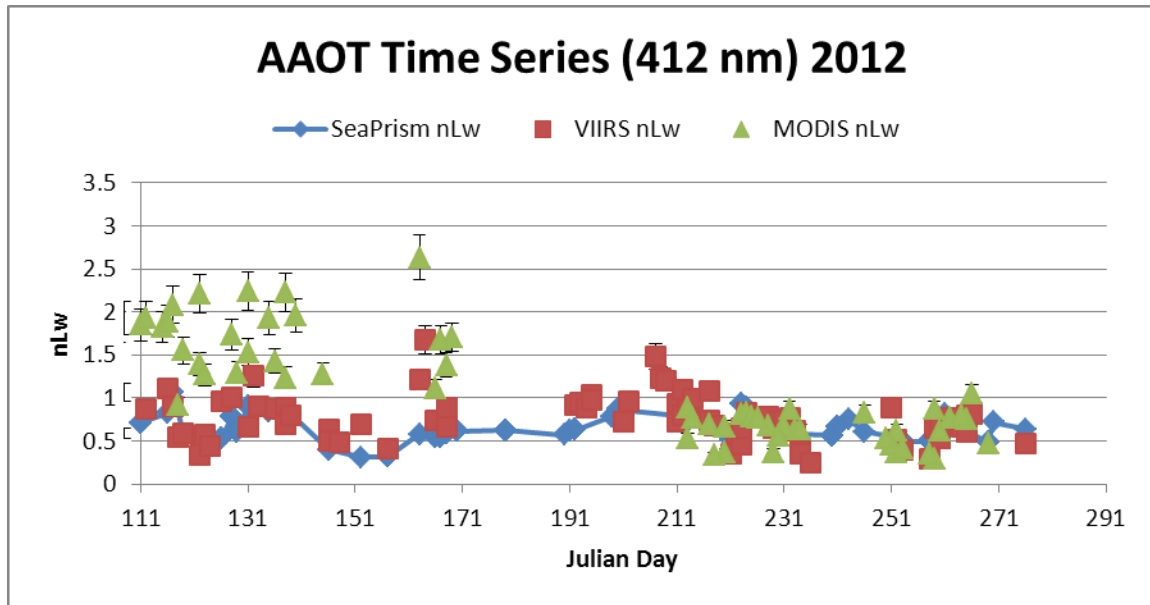


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Figure 5 shows the time series of data available at the 490 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data between day 111 and 211 for MODIS are produced using ver 5 processing, notice this channel was not affected by the degradation of the lower wavelength channels therefore the updated look up table (LUT) does not have the dramatic effect of improvement as seen in the shorter wavelength channels. Generally the VIIRS and MODIS data seems reasonable with some anomalies likely due to the dynamics in the relative contributions of CDOM and SPM in these coastal waters, as well as some influence of the biological water constituents.

Figure 6 shows the time series of data available at the 551 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. In the green coastal waters of Venice, this channel exhibits a strong signal, therefore most data show by both satellites are within the operational requirement (10%) of the “truth” even before bias corrections.

Figure 7 shows the time series of data available at the 668 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data is close to the operational limits of the VIIRS sensor ( $0.10 - 10 \text{ W m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$ ) and the signal is noisier. A bias (offset) is evident in the time series in both the VIIRS and MODIS data, the regression is linear as shown in Table 1.



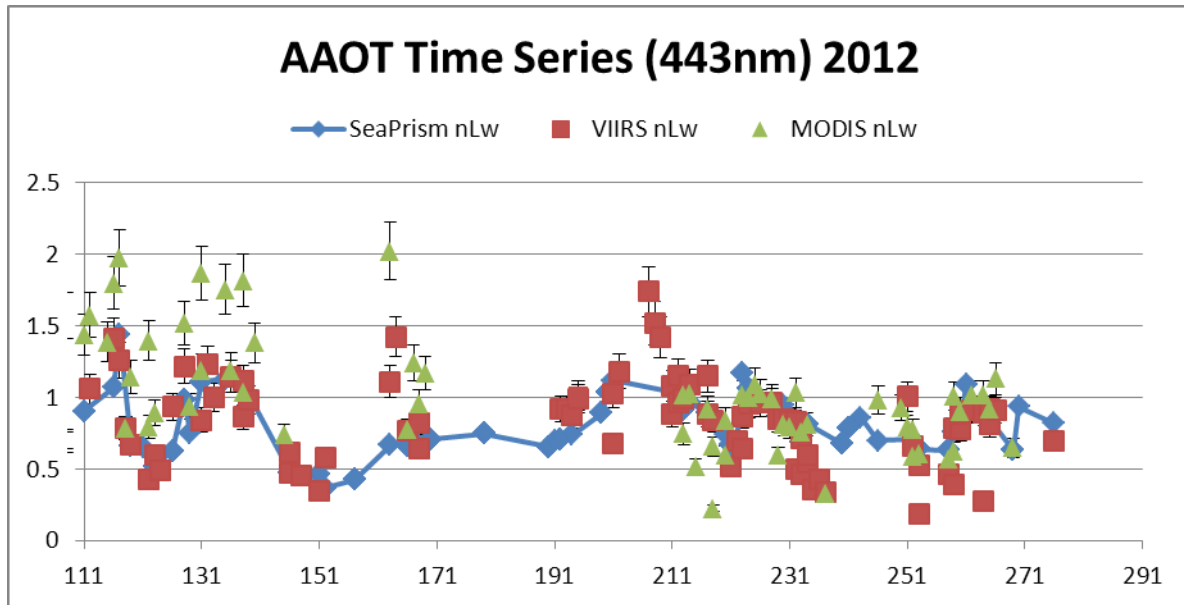


Figure 4 shows the time series of data available at the 443 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data between day 111 and 211 for MODIS are produced using ver 5 processing. MODIS data beyond Julian Day 211 was processed with the updated MODIS ver 6 processing. Generally the VIIRS data seems reasonable with some high and low outliers which could be due to the highly variable optical conditions known to occur in coastal waters, such as advection, biological patchiness, multiple scattering effects. The 410 and 443 wavelengths are subject to the greatest variability of water composition (colored dissolved organic matter, CDOM; suspended particulate matter, SPM; and biologics).

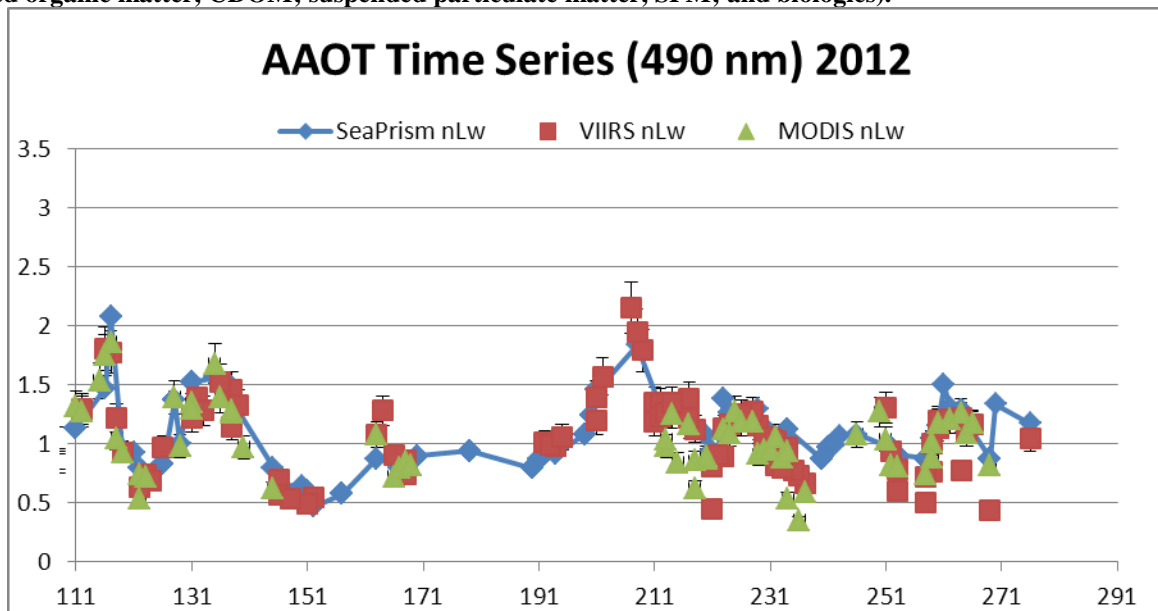


Figure 5 shows the time series of data available at the 490 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data between day 111 and 211 for MODIS are produced using ver 5 processing, notice this channel was not affected by the degradation of the lower wavelength channels therefore the updated look up table (LUT) does not have the dramatic effect of improvement as seen in the shorter wavelength channels. Generally the VIIRS and MODIS data seems reasonable with some anomalies likely due to the dynamics in the relative contributions of CDOM and SPM in these coastal waters, as well as some influence of the biological water constituents.

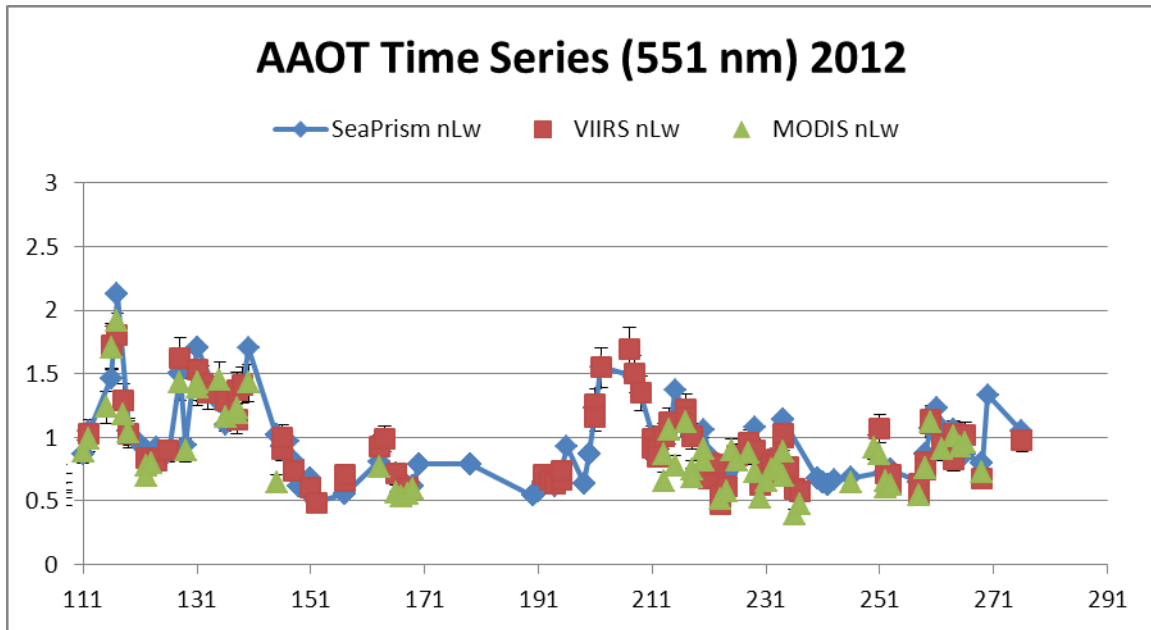


Figure 6 shows the time series of data available at the 551 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. In the green coastal waters of Venice, this channel exhibits a strong signal, therefore most data show by both satellites are within the operational requirement (10%) of the “truth” even before bias corrections.

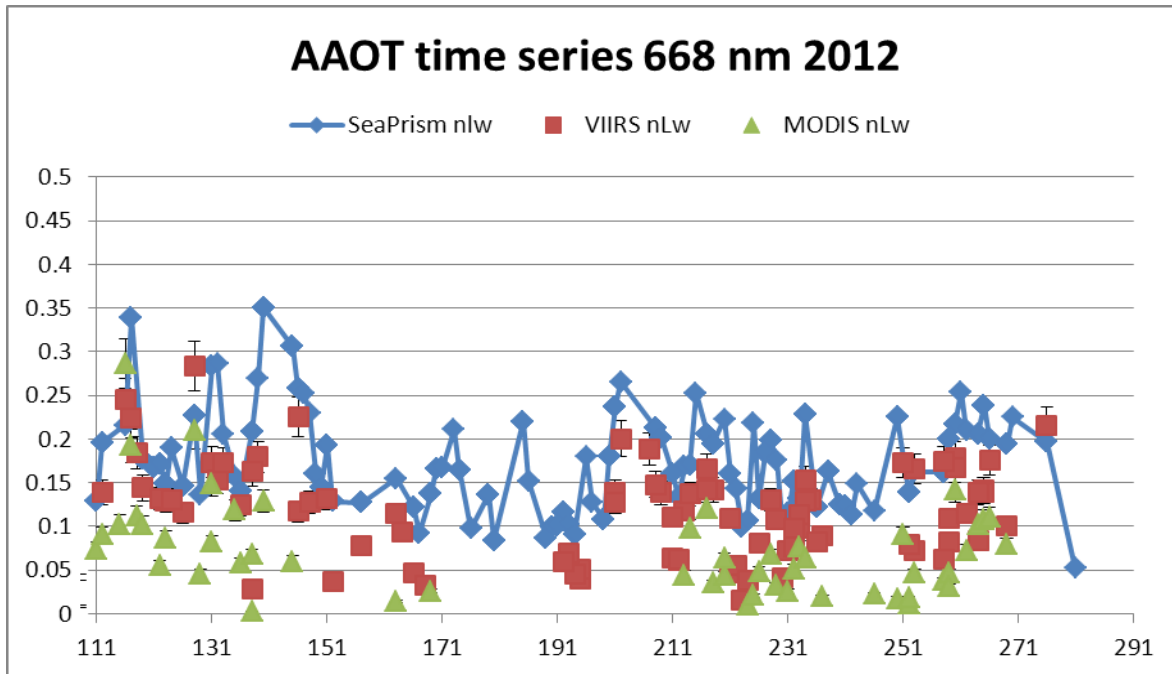


Figure 7 shows the time series of data available at the 668 nm channel from the AAOT *in situ* sensor (mean nLw), the 25km mean VIIRS nLw, and the 25km mean MODIS nLw. The data is close to the operational limits of the VIIRS sensor ( $0.10 - 10 \text{ W m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$ ) and the signal is noisier. A bias (offset) is evident in the time series in both the VIIRS and MODIS data, the regression is linear as shown in Table 1.

Graphics depicting the regression analysis are provided for the matchups at 488 nm and 551 nm as these wavelengths define the bounds of optimal visibility (Figure 8 and Figure 9). Full statistics are provided for all wavelengths in Table 1.

Figure 8 shows the matchups of the mean nLw values shown in the time series Figure 5. The blue represents the SeaPrism (*x-axis*) to MODIS (*y-axis*) comparison. The red represents the SeaPrism (*x-axis*) to VIIRS (*y-axis*) comparison. The green represents the MODIS (*x-axis*) to VIIRS (*y-axis*) comparison. The bias is shown as the slope of the regressions with color corresponding boxes. Based on the bias values for the AAOT site and the 488 nm wavelength, it is shown that MODIS is within 10% of the SeaPrism, VIIRS is within 4% of the SeaPrism and VIIRS is within 7% of the MODIS reading. The VIIRS to MODIS comparison gives some insight to what can be expected in terms of performance for cross-platform stability. (Recall this is the mean nLw of a 5x5km box vice the expanded scene provided by a satellite to satellite comparison.)

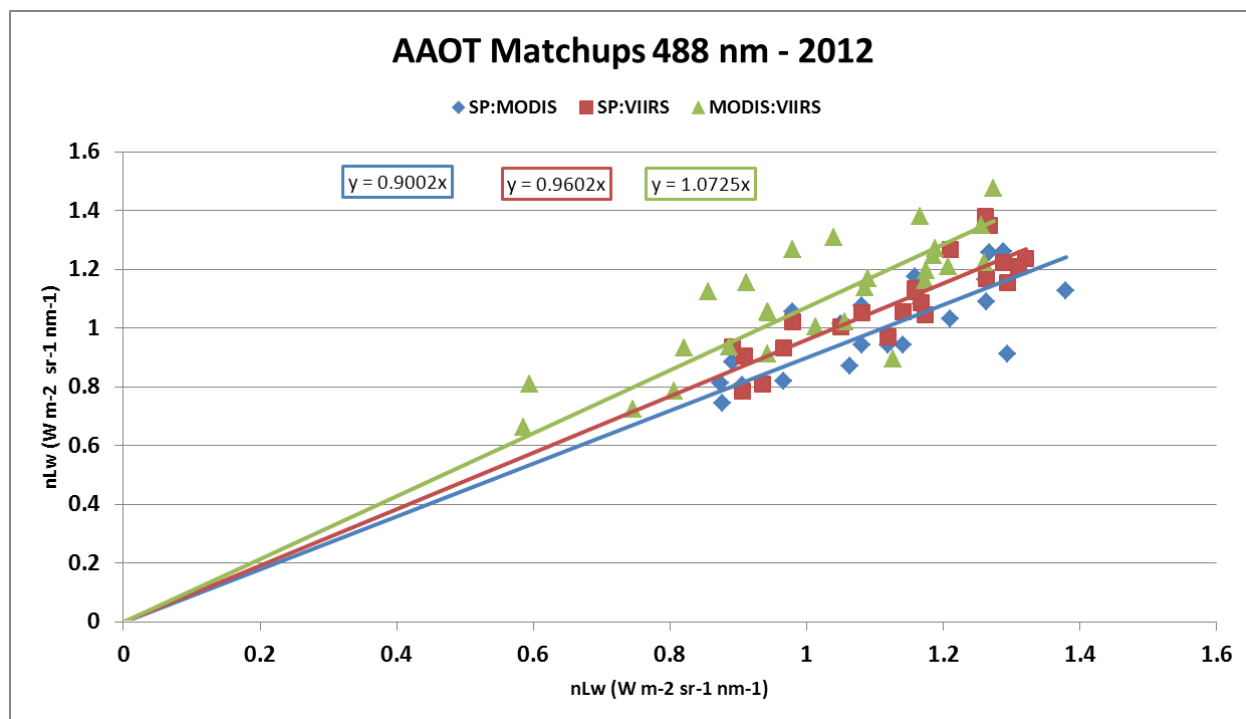


Figure 8 shows the matchups of the mean nLw values shown in the time series Figure 5. The blue represents the SeaPrism (*x-axis*) to MODIS (*y-axis*) comparison. The red represents the SeaPrism (*x-axis*) to VIIRS (*y-axis*) comparison. The green represents the MODIS (*x-axis*) to VIIRS (*y-axis*) comparison. The bias is shown as the slope of the regressions with color corresponding boxes. Based on the bias values for the AAOT site and the 488 nm wavelength, it is shown that MODIS is within 10% of the SeaPrism, VIIRS is within 4% of the SeaPrism and VIIRS is within 7% of the MODIS reading. The VIIRS to MODIS comparison gives some insight to what can be expected in terms of performance for cross-platform stability. (Recall this is the mean nLw of a 5x5km box vice the expanded scene provided by a satellite to satellite comparison.)

Figure 9 shows the matchups of the mean nLw values shown in the time series Figure 6. The blue represents the SeaPrism (*x-axis*) to MODIS (*y-axis*) comparison. The red represents the SeaPrism (*x-*

axis) to VIIRS (y-axis) comparison. The green represents the MODIS (x-axis) to VIIRS (y-axis) comparison. The bias is shown as the slope of the regressions with color corresponding boxes. Based on the bias values for the AAOT site and the 551 nm wavelength, it is shown that MODIS is within 10% of the SeaPrism, VIIRS is within 5% of the SeaPrism and VIIRS is within 10% of the MODIS reading.

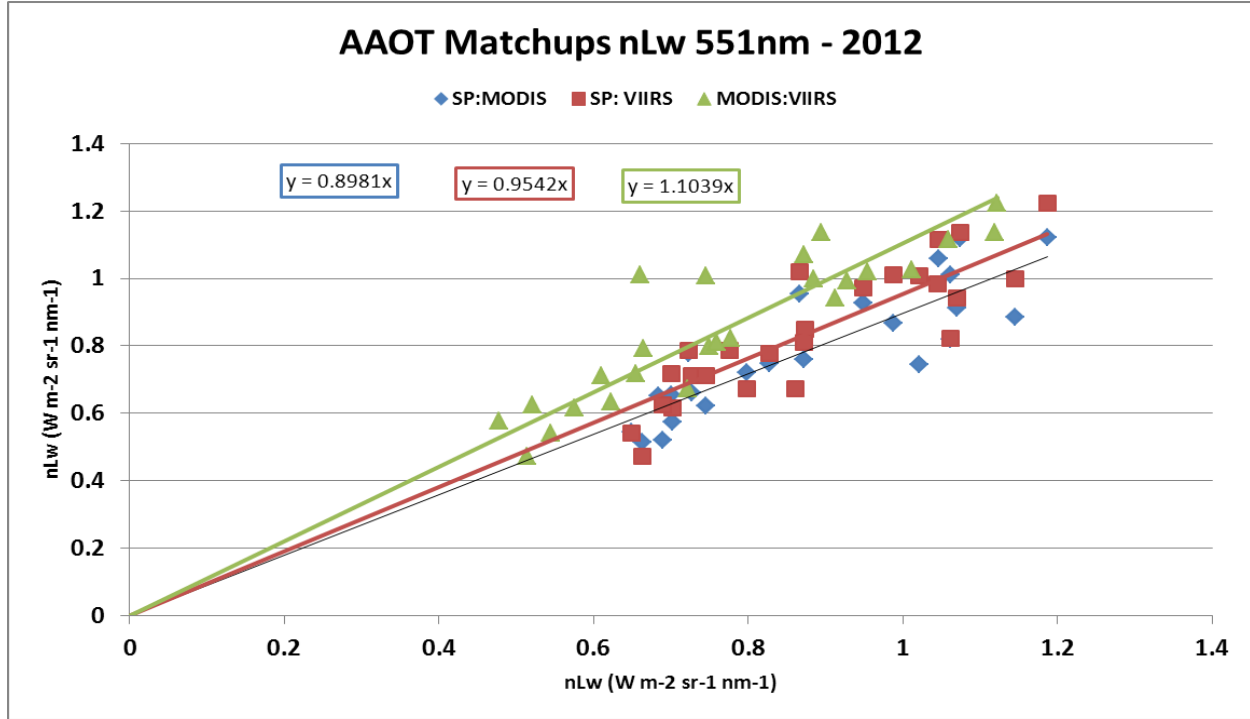


Figure 9 shows the matchups of the mean nLw values shown in the time series Figure 6. The blue represents the SeaPrism (x-axis) to MODIS (y-axis) comparison. The red represents the SeaPrism (x-axis) to VIIRS (y-axis) comparison. The green represents the MODIS (x-axis) to VIIRS (y-axis) comparison. The bias is shown as the slope of the regressions with color corresponding boxes. Based on the bias values for the AAOT site and the 551 nm wavelength, it is shown that MODIS is within 10% of the SeaPrism, VIIRS is within 5% of the SeaPrism and VIIRS is within 10% of the MODIS reading.

	SP:MODIS		SP:VIIRS		MODIS:VIIRS	
wavelength	slope	r <sup>2</sup>	slope	r <sup>2</sup>	slope	r <sup>2</sup>
410	1.0205	0.9634	1.0444	0.9640	0.9733	0.9140
443	0.9905	0.9821	0.9223	0.9820	0.9243	0.9554
488	0.9002	0.9911	0.9602	0.9954	1.0725	0.9879
551	0.8981	0.9872	0.9542	0.9885	1.1039	0.9888
671	0.4157	0.8252	0.7060	0.9313	1.3780	0.9837

Table 1 AAOT Match-up: slope and correlation coefficient (r<sup>2</sup>) for each channel of the spectral remote sensing reflectance between the *in situ* with VIIRS and MODIS. For assessment purposes when a slope = 1 the relationship is statistically perfect, degrees off of 1 indicate a bias between 'truth' and satellite. For the MODIS:VIIRS comparison, the MODIS is regarded as the truth only because it is a heritage satellite.

### 3.1.3 Oceanographic cruise data: South Florida Bight

In February 2008 data was taken off the coast of South Florida and compared to the results of VIIRS processed by both NRL and the Interface Data Processing Segment (IDPS)<sup>8</sup>. Ocean color algorithms for the navy are unique. Table 2 provides a summary of the algorithm differences between the IDPS (L2Gen) and APS (N2Gen) processing.

	IDPS	N2Gen/APS
Aerosol LUT model	Wang (12 models)	Ahmad/Fraser (80 models)
Correction Algorithm Basis	Gordon and Wang	Gordon Wang with NIR correction
Gaseous Absorption Species	O <sub>3</sub> , H <sub>2</sub> O, and other constant species	same as NASA O3 H2O and O2
"Bright Pixel" correction	no	Bailey/2010
Gaseous Absorption RSR (detector averaged)	Absorption coefficients based on V2 Fused RSR	Absorption coefficients based on "V3 New-Fused" RSR
Solar Spectrum	MODTRAN	Thullier 2003
Rayleigh LUT	Generated by Wang using TVAC RSR	following NASA
Diffuse Transmittance	2 component Gordon Yang (Center wavelength only)	following NASA/Fraser
Glint Mask model/angle	VIIRS Cloud Mask / 36 degrees cone	Cox Monk/combination of 36 and other things
Sun glint correction / threshold	Gordon Glint Mask /0.005 with contamination correction	Bailey and Wang/0.01 with contamination correction
Wind speed input data	NCEP GFS/forecast data	"climatology for the real time"
Cloud Mask	VIIRS	using same as Wang right now
Whitecap Correction (wind speed cap)	8 m/s	8 m/s
Bright Pixel (Stray Light Exclusion) Algo.	Quality flag based on scattered light	same as MSL12
How often F-tables are implemented?	weekly	weekly
Polarization LUT	Ambient Test data	same as NASA
Polarization LUT Band or Detector	Detector dependent	detector averaged
RSR used in Rayleigh gain LUT	MX5.3 (Fused RSR) / MX6.2 (New-Fused RSR)	same as Wang
Sensor Zenith Angle exclusion	53 degrees	57 degrees
Solar Zenith Angle exclusion	70 degrees	70degrees
OCC		
Land/Water Mask	QST 2001 LWM and 2005 MODIS	UMB using the full resolution 250m LWM
Chlorophyll Algorithm	OC3V	OC3V
Chlorophyll Coefficients	NASA coefficients	NASA coefficients
IOP algorithm	Carder	QAA

**Table 2 provides a summary of the algorithm differences between the IDPS (L2Gen) and APS (N2Gen) processing.**

<sup>8</sup> The IDPS processes JPSS satellite data to provide the environmental data products (Scientific Data Records, SDRs and Environmental Data Records, EDRs).

Figure 10 shows data collected on 28 Feb 2012 from a very near-shore station. The remote sensing reflectances generated with NRL processing of VIIRS using LUT006e and LUT007a are shown as compared to results of the NRL MODIS-AQUA and the IDPS VIIRS and MODIS. The NRL algorithms return higher reflectance at the blue wavelengths (412nm, 440 nm) which is likely resulting in the difference in chlorophyll products shown in the bottom three panels: MODIS chl, NRL VIIRS chl, IDPS VIIRS chl, notice the absence of ‘red/orange’ in the center of the NRL panel. This is being investigated further with the *in situ* data.

Figure 11 shows data collected on 29 Feb 2012 at deeper water conditions. Notice the reflectance values of all instrumentation are reasonably convergent with the exception of the NRL MODIS, Aqua where the elevated 410 nm and 440 nm are due to the blue wavelength calibration issues which are now corrected with the AOPS, MODIS v 6.0 processing and incomplete removal of glint or atmospheric light contributions. The bottom three panels show the calculated chlorophyll from MODIS, NRL VIIRS and IDPS VIIRS. The NRL chlorophyll is somewhat elevated as compared to the MODIS and IDPS. This is being investigated further. It has not been determined whether or not the daily LUT changes are a factor in this result.

Table 3 shows the South Florida Cruise Match-up: Correlation coefficient ( $r^2$ ) and slope for each channel of the spectral remote sensing reflectance between the *in situ* (ASD and HyperPro) with VIIRS (IDPS and NRL-I2gen) and MODIS. As seen in comparing the  $r^2$  values the HyperPro shows a strong correlation with both the IDPS and NRL data, *with slightly better correlation in the NRL 412*. The correlation between the ASD data and coincident satellites is slightly higher with the IDPS products. The *in situ* data indicates a slipping in the correlation between itself and the MODIS 410 nm channel. This gives indication that the MODIS 410 data may be suspect for high quality analyses of products that incorporate data from that wavelength.

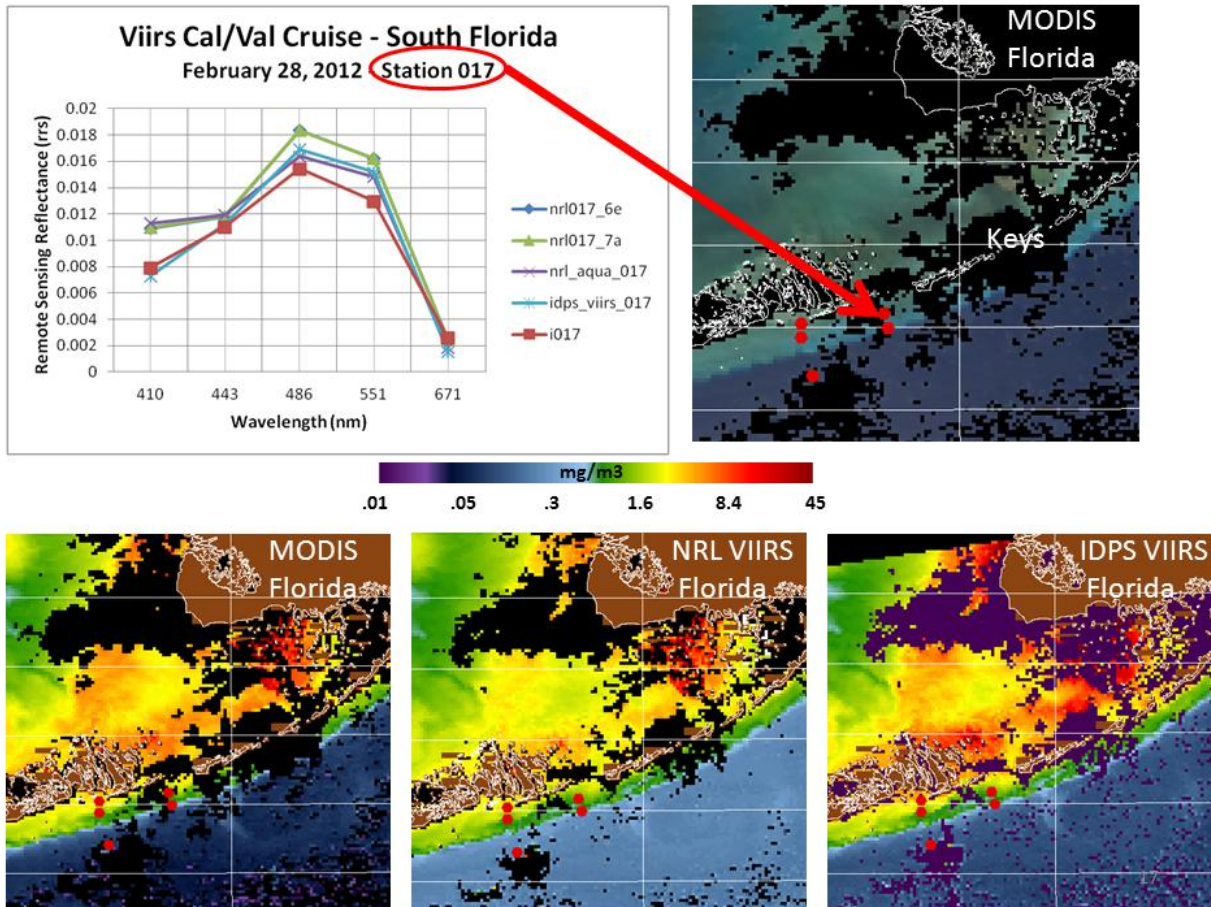


Figure 10 shows data collected on 28 Feb 2012 from a very near-shore station. The remote sensing reflectances generated with NRL processing of VIIRS using LUT006e and LUT007a are shown as compared to results of the NRL MODIS-AQUA and the IDPS VIIRS and MODIS. The NRL algorithms return higher reflectance at the blue wavelengths (412nm, 440 nm) which is likely resulting in the difference in chlorophyll products shown in the bottom three panels: MODIS chl, NRL VIIRS chl, IDPS VIIRS chl, notice the absence of ‘red/orange’ in the center or the NRL panel. This is being investigated further with the *in situ* data.



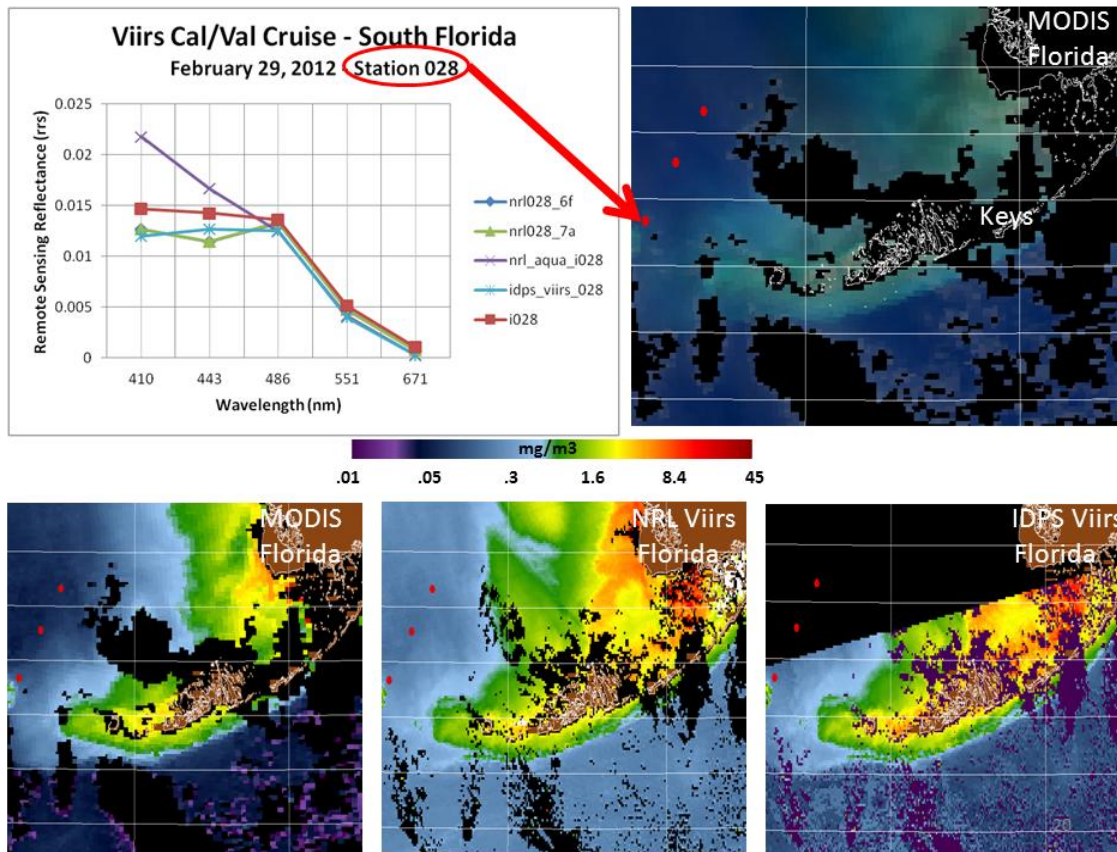


Figure 11 shows data collected on 29 Feb 2012 at deeper water conditions. Notice the reflectance values of all instrumentation are reasonably convergent with the exception of the NRL MODIS, Aqua where the elevated 410 nm and 440 nm are due to the blue wavelength calibration issues which are now corrected with the AOPS, MODIS v 6.0 processing and incomplete removal of glint or atmospheric light contributions. The bottom three panels show the calculated chlorophyll from MODIS, NRL VIIRS and IDPS VIIRS. The NRL chlorophyll is somewhat elevated as compared to the MODIS and IDPS. This is being investigated further. It has not been determined whether or not the daily LUT changes are a factor in this result.



	Hypro vs IDPS		Hypro vs L2GEN		ASD - L2gen		ASD-IDPS		ASD vs Aqua		Hyperpro vs Aqua	
channel	r2	slope	r2	slope	r2	slope	r2	slope	r2	slope	r2	slope
410	0.8628	0.8752	0.9071	1.0177	0.8414	0.9639	0.8364	0.7994	0.5753	1.2016	0.4575	1.2782
443	0.9848	0.9329	0.9848	0.9058	0.9468	0.9072	0.9766	0.9125	0.9202	0.9692	0.8922	0.9796
488	0.9981	0.9772	0.9964	0.9762	0.9735	1.0503	0.9912	0.9964	0.9888	0.9115	0.9914	0.8727
551	0.9895	0.9603	0.9850	0.9838	0.9635	1.1198	0.9759	1.0767	0.9804	0.9281	0.9779	0.873
671	0.9953	0.7362	0.9959	0.9368	0.8992	1.0056	0.9613	0.7327	0.9712	0.576	0.9792	0.6486

Table 3 shows the South Florida Cruise Match-up: Correlation coefficient ( $r^2$ ) and slope for each channel of the spectral remote sensing reflectance between the *in situ* (ASD and HyperPro) with VIIRS (IDPS and NRL-l2gen) and MODIS. As seen in comparing the  $r^2$  values the HyperPro shows a strong correlation with both the IDPS and NRL data, with *slightly better correlation in the NRL 412*. The correlation between the ASD data and coincident satellites is slightly higher with the IDPS products. The *in situ* data indicates a slipping in the correlation between itself and the MODIS 410 nm channel. This gives indication that the MODIS 410 data may be suspect for high quality analyses of products that incorporate data from that wavelength.

## 3.2 Cross Platform (satellite to satellite) matchups

Beyond traditional ground truth techniques, NPP ocean color products can be evaluated by direct comparison with existing satellite products such as MODIS. This enables cross-platform capabilities and the technique will rapidly provide consistent data sets from which global metrics of ocean color products can be defined. An additional advantage is that it will provide validation of products in critical coastal regions where *in situ* data is not available.

Standard operational products produced from MODIS are used for validation. Additionally, chlorophyll products generated by the NASA and NOAA IDPS will be used. Comparisons will provide an assessment of the robustness of the NPP products and provide an additional determination of the impact of changes in calibration during the mission in coastal and offshore as well as in specific regions.

### 3.2.1 West Mediterranean

Figure 12 shows the comparison of the nLw product at 488 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The scaling of the bias is presented in Figure 13 and Table 4.

Figure 13 shows the regression analysis of Western Mediterranean nLw product at all wavelengths from the VIIRS (y-axis) and MODIS (x-axis) using AOPS v4.8. The results indicate the sensors perform well in relation to one another with a bias evident at all wavelengths. The bias is presented in Table 4.

Table 4 summarizes the statistical results of the MODIS to VIIRS matchups for the Western Mediterranean example provided. The strong correlation coefficient suggests high confidence in the

relative performance of these systems. The slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results.

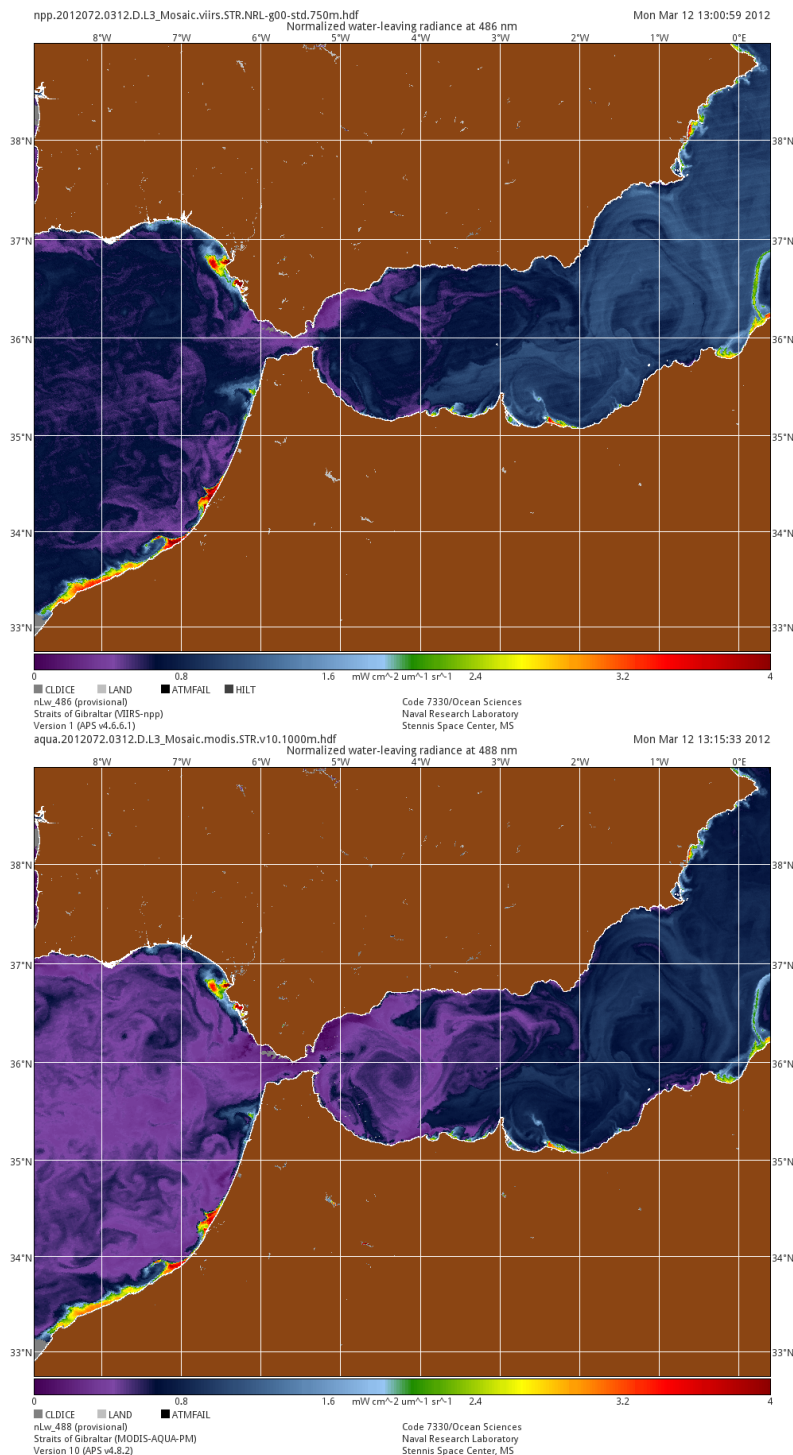


Figure 12 shows the comparison of the nLw product at 488 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The scaling of the bias is presented in Figure 13 and Table 4.

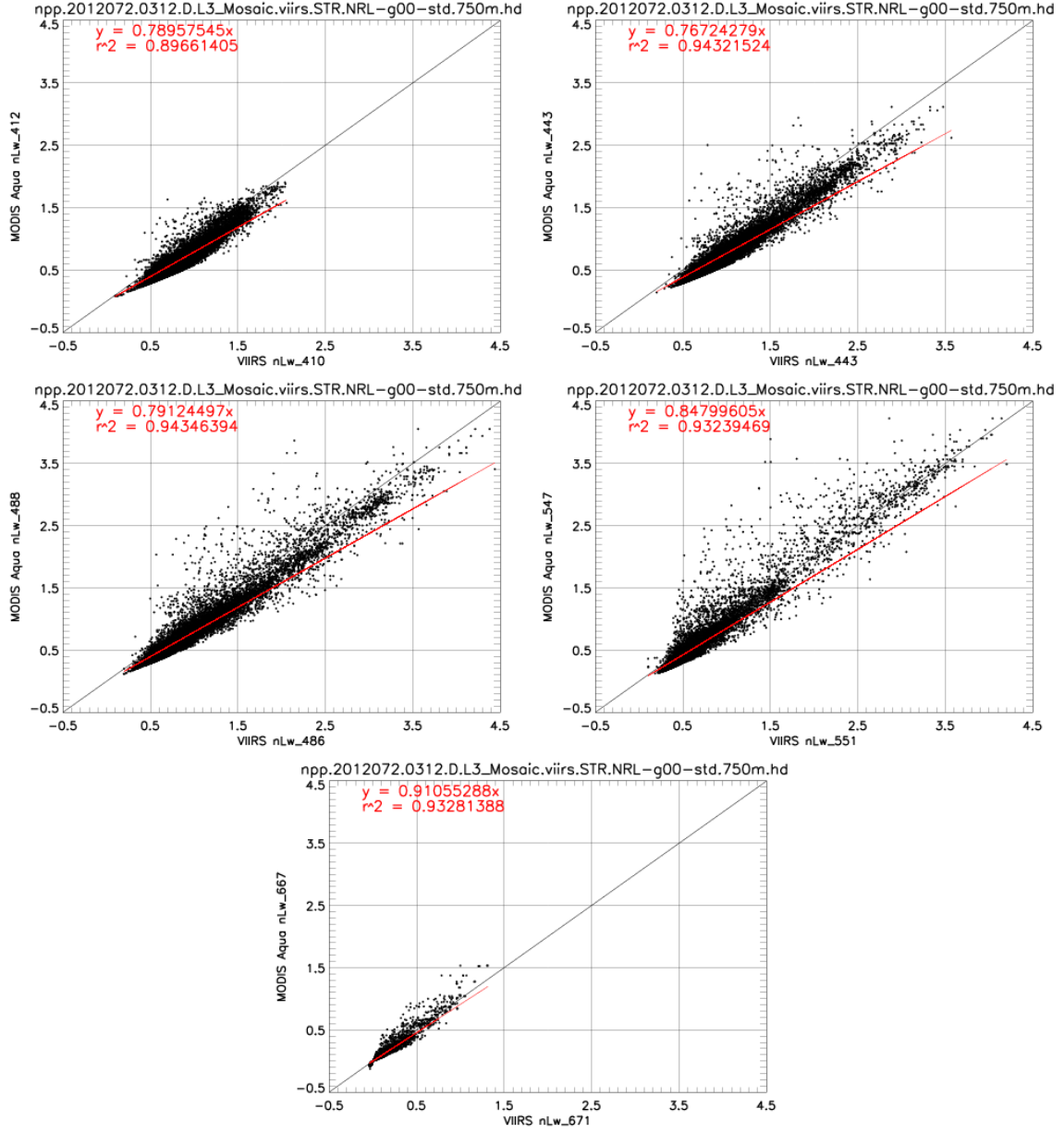


Figure 13 shows the regression analysis of Western Mediterranean nLw product at all wavelengths from the VIIRS (y-axis) and MODIS (x-axis) using AOPS v4.8. The results indicate the sensors perform well in relation to one another with a bias evident at all wavelengths. The bias is presented in Table 4.

Western Mediterranean		
Wavelength (MODIS/VIIRS)	slope	r <sup>2</sup>
412/410	0.78957545	0.89661405
443/443	0.76724279	0.94321524
488/486	0.79124497	0.94346394
547/551	0.84799605	0.93239469
667/671	0.91055288	0.93281388

Table 4 summarizes the statistical results of the MODIS to VIIRS matchups for the Western Mediterranean example provided. The strong correlation coefficient suggests high confidence in the relative performance of these systems. The slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results.

### 3.2.2 Chesapeake Bay

Figure 14 shows the comparison of the nLw product at 551/547 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The bias is calculated in Figure 16 and Table 5.

Figure 16 shows the comparison of United States West Coast the nLw product at 551/547 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The bias is calculated in Figure 17 and Table 6.

Table 5 summarizes the statistical results of the MODIS to VIIRS matchups for the Chesapeake Bay example provided. The strong correlation coefficient suggests high confidence in the relative performance of these systems, with the exception of the 412/410 channels. For all channels, the slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results at most wavelengths. With respect to the 412/410 the slope is 5% from “perfect = 1”, therefore the low correlation is more likely due to high natural variability of suspended particulate and dissolved organics in the area of interest.

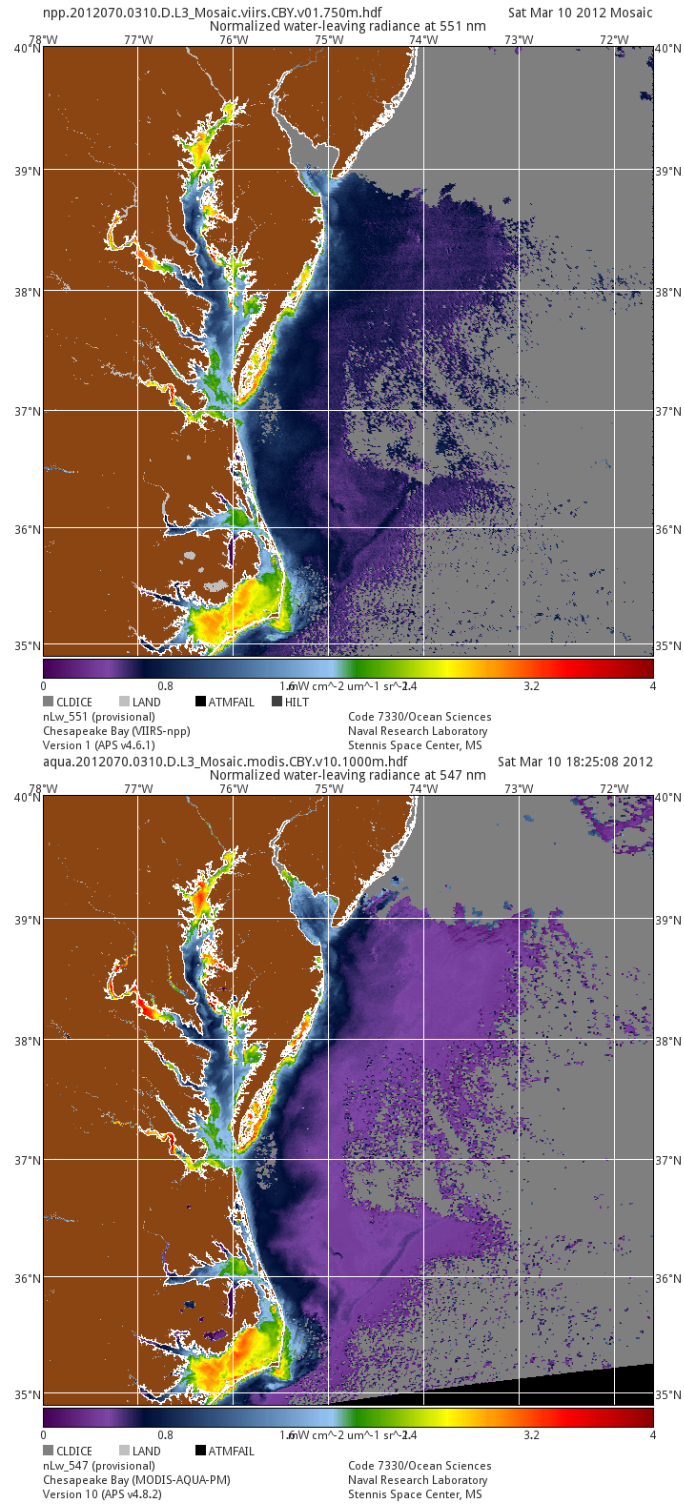


Figure 14 shows the comparison of the nLw product at 551/547 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The bias is calculated in Figure 16 and Table 5.

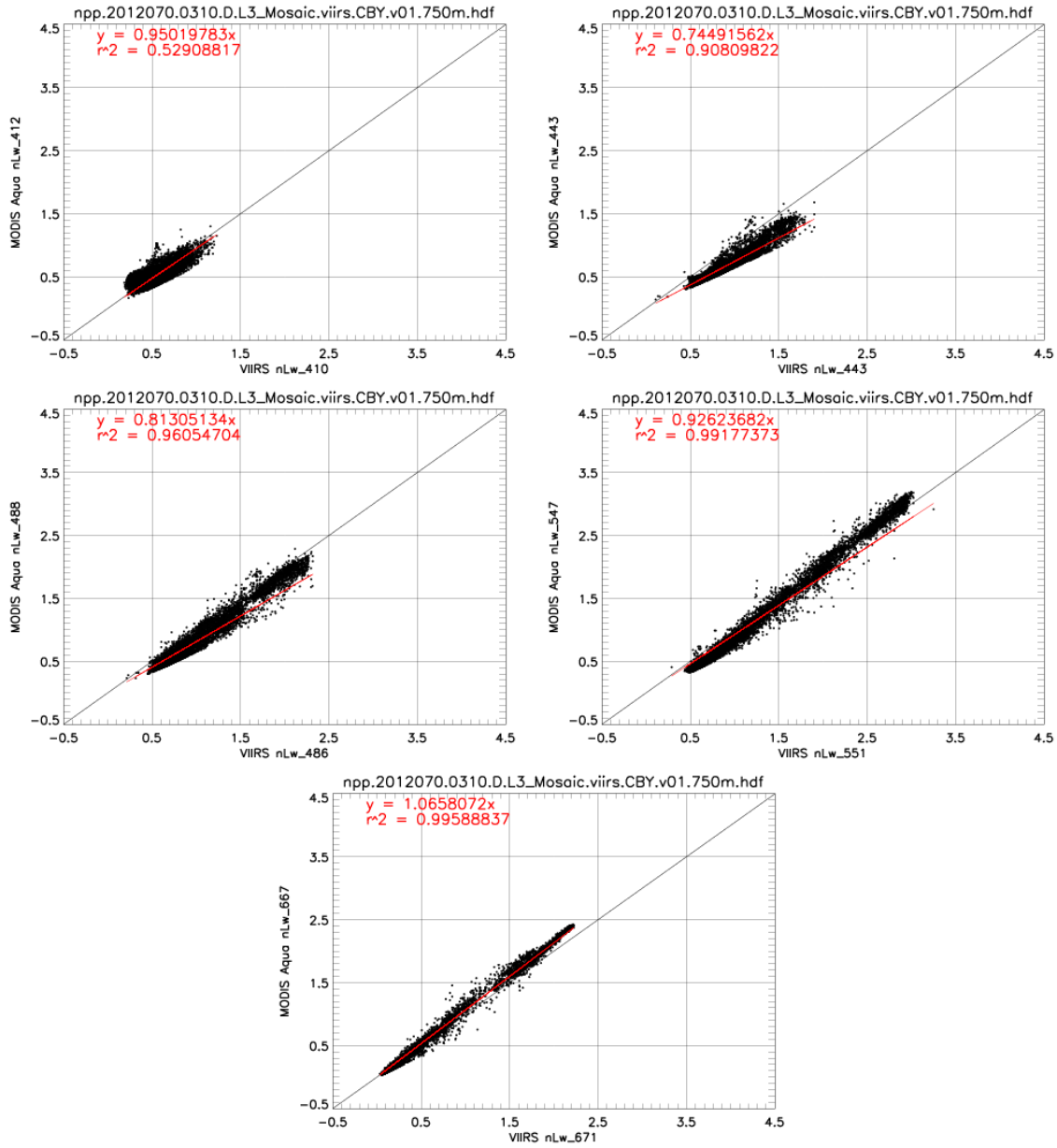


Figure 15 shows the regression analysis of Chesapeake Bay the nLw product at all wavelengths from the VIIRS (y-axis) and MODIS (x-axis) using AOPS v4.8. The results indicate the sensors perform well in relation to one another. There is a bias at all wavelengths. The blue 412 nm and 443 nm bands show greater scatter which is likely the result of variation in atmosphere and the in water constituents; CDOM, SPM and biological patchiness.

Chesapeake Bay		
Wavelength (MODIS/VIIRS)	slope	r <sup>2</sup>
412/410	0.95019783	0.52908817
443/443	0.74491562	0.90809822
488/486	0.81305134	0.96054704
547/551	0.92623682	0.99177373
667/671	1.0658072	0.99588837

Table 5 summarizes the statistical results of the MODIS to VIIRS matchups for the Chesapeake Bay example provided. The strong correlation coefficient suggests high confidence in the relative performance of these systems, with the exception of the 412/410 channels. For all channels, the slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results at most wavelengths. With respect to the 412/410 the slope is 5% from “perfect = 1”, therefore the low correlation is more likely due to high natural variability of suspended particulate and dissolved organics in the area of interest.

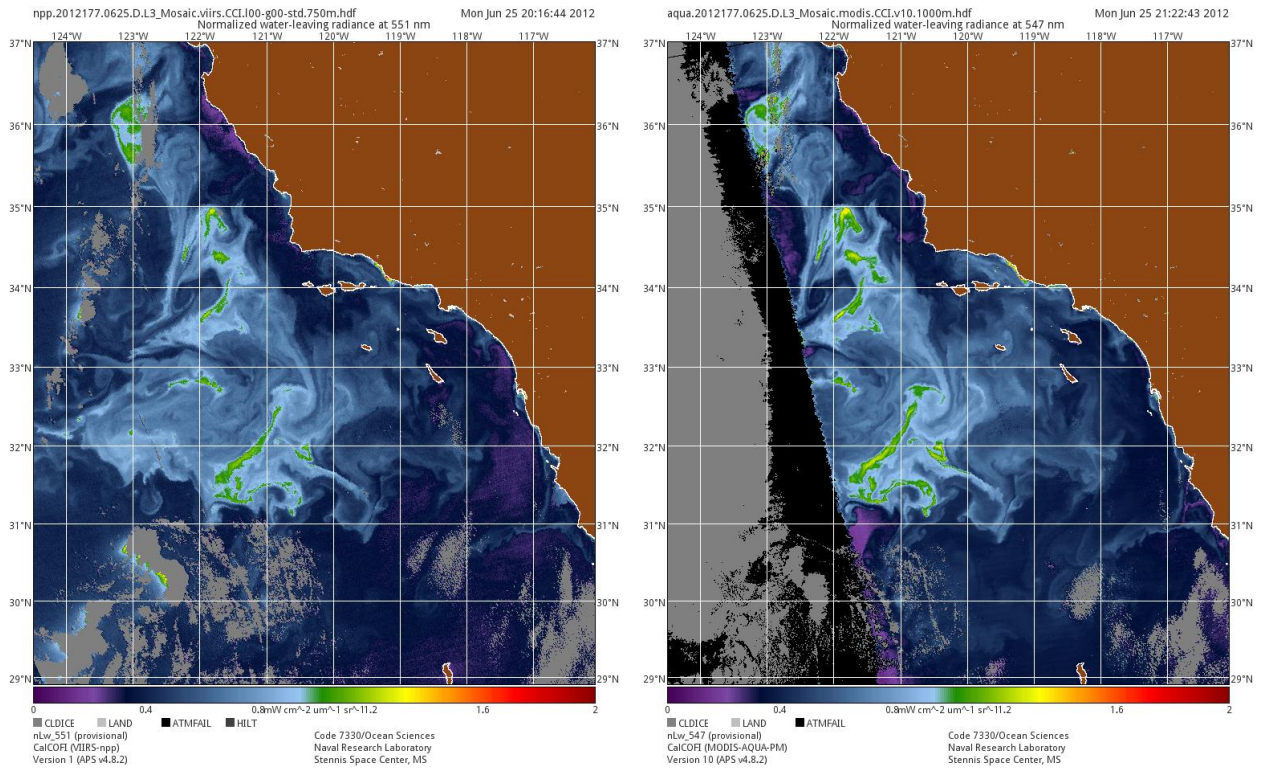
### 3.2.3 US West Coast

Figure 16 shows the comparison of United States West Coast the nLw product at 551/547 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The bias is calculated in Figure 17 and Table 6.

Figure 17 shows the regression analysis of United States West Coast the nLw product at all wavelengths from the VIIRS (y-axis) and MODIS (x-axis) using AOPS v4.8. The results indicate the sensors perform well in relation to one another. There is a bias at all wavelengths. The blue 412 nm and 443 nm bands show greater scatter which is likely the result of variation in atmosphere and the in water constituents; CDOM, SPM and biological patchiness.

Table 6 summarizes the statistical results of the MODIS to VIIRS matchups for the US West Coast example provided above. The strong correlation coefficient suggests high confidence in the relative performance of these systems. The slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results at some wavelengths.





**Figure 16 shows the comparison of United States West Coast the nLw product at 551/547 nm generated from the VIIRS (top) and MODIS (bottom) using AOPS v4.8. The basic oceanographic features are evident in each image as is the difference in magnitude of the nLw measurement. The bias is calculated in Figure 17 and Table 6.**



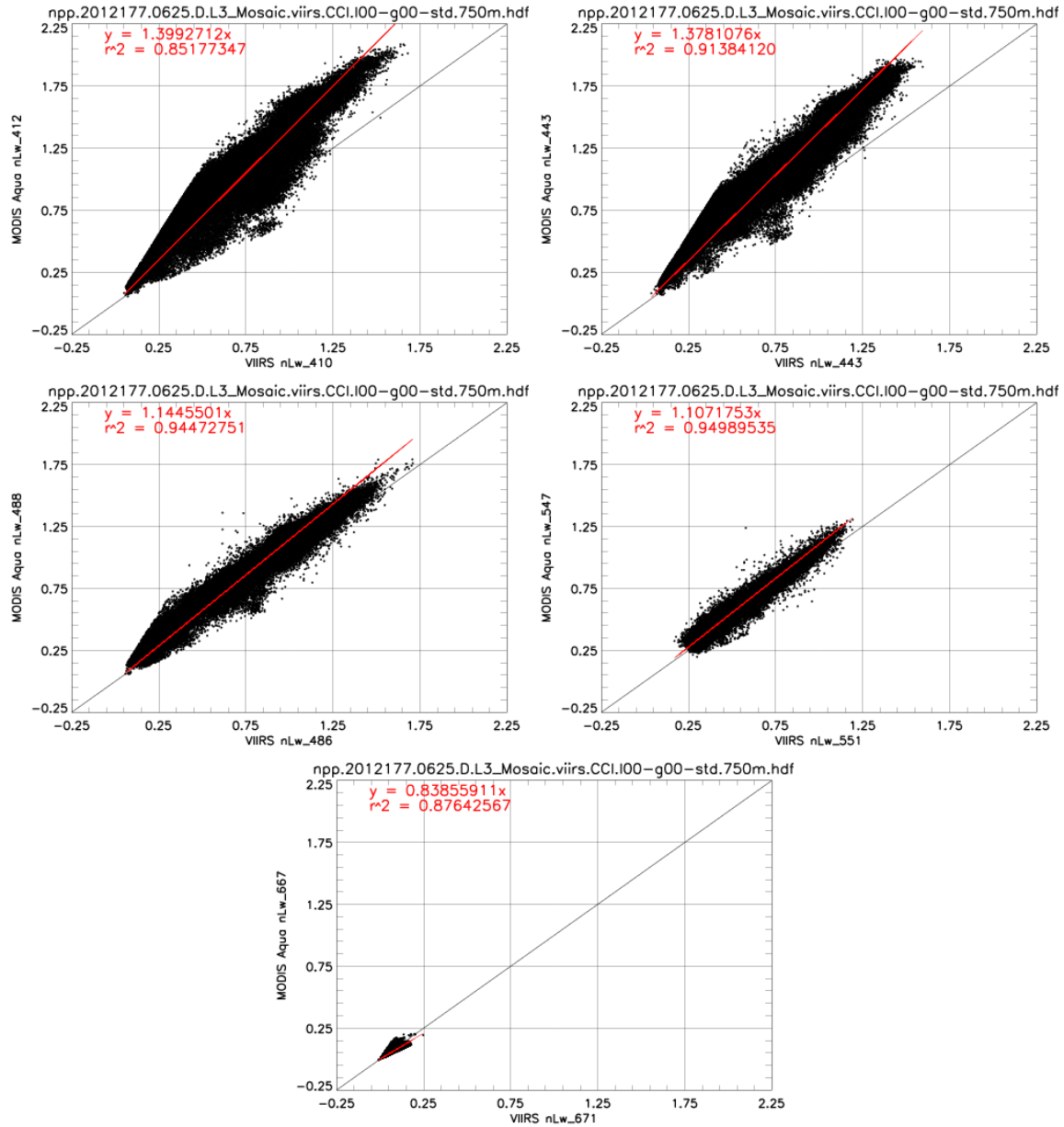


Figure 17 shows the regression analysis of United States West Coast the nLw product at all wavelengths from the VIIRS (y-axis) and MODIS (x-axis) using AOPS v4.8. The results indicate the sensors perform well in relation to one another. There is a bias at all wavelengths. The blue 412 nm and 443 nm bands show greater scatter which is likely the result of variation in atmosphere and the in water constituents; CDOM, SPM and biological patchiness.

US West Coast		
Wavelength (MODIS/VIIRS)	slope	r <sup>2</sup>
412/410	1.3992712	0.85177347
443/443	1.3781076	0.91384120
488/486	1.145501	0.94472751
547/551	1.1071753	0.94989535
667/671	0.83855911	0.87642567

Table 6 summarizes the statistical results of the MODIS to VIIRS matchups for the US West Coast example provided above. The strong correlation coefficient suggests high confidence in the relative performance of these systems. The slope indicates the bias between the systems and suggests an on-orbit vicarious calibration would improve the results at some wavelengths.

### 3.2.4 GOM – chlorophyll cruise

The Gulf of Mexico chlorophyll cruise has been added to this report to show the correlation of the chlorophyll products and demonstrate how the N2Gen<sup>9</sup> upgrades in AOPS v4.8 improve the matchups.

Figure 18 shows a VIIRS image of the Gulf of Mexico with oceanographic cruise stations 1 – 3 in an offshore transect. The VIIRS data was processed using the updated N2Gen and analyzed with the previous version of N2Gen, the IDPS processing and NASA’s processing technique.

Figure 19 and Figure 20 show the nLw and chlorophyll products for station 1. The upgrades made to N2Gen (viirs nrl2) show improved spectral accuracy compared to the other processing methods.

<sup>9</sup> The terms N2Gen and L2Gen are often used interchangeably by scientists, mostly in verbal communication. Specifically, the N2Gen nomenclature is used to distinguish navy modifications to level 2 generator (L2Gen) however when working with NASA and NOAA, the tendency is to use their terminology. Technically NRL and NAVOCEANO use the N2Gen process.

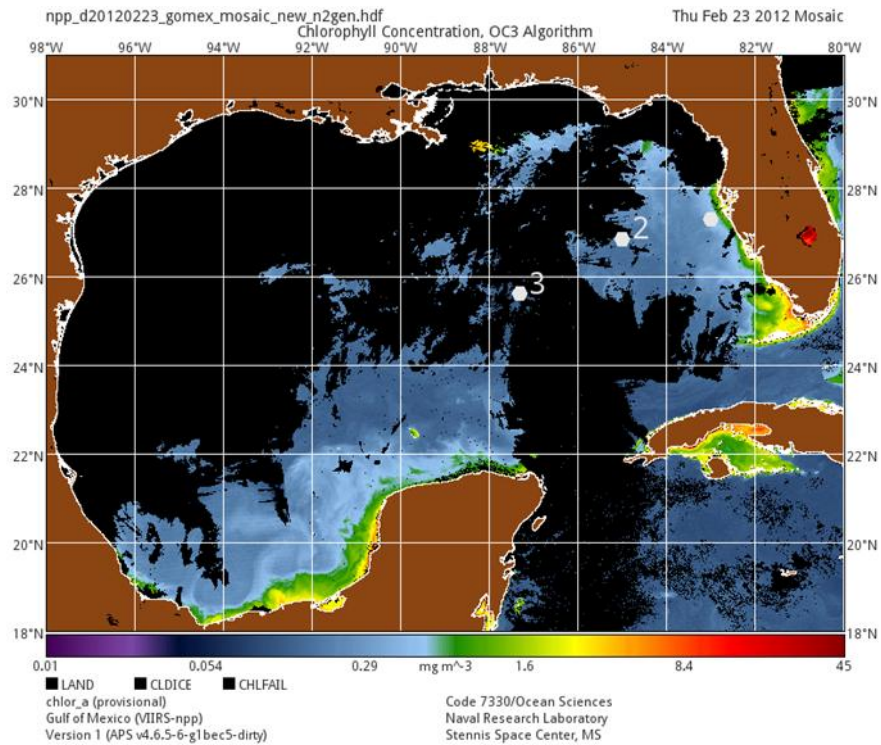


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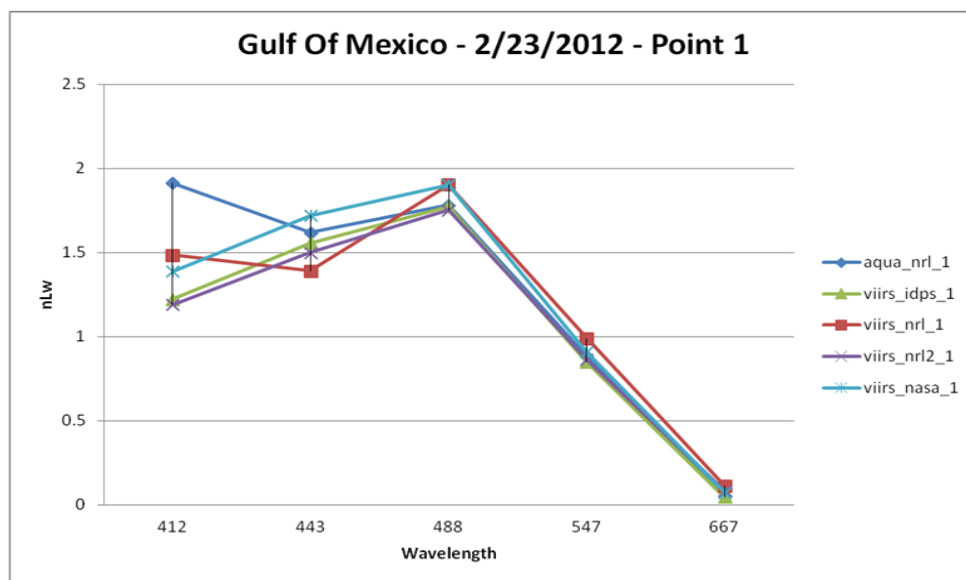


Figure 19 shows the spectral radiance (nLw) results at Point 1 from Figure 18 for various satellite processing techniques. Standard navy processing for MODIS is given as the blue line (aqua\_nrl\_1). The VIIRS data were derived by the IDPS, nrl\_1 (old N2Gen), nrl2\_1 (new N2Gen), and NASA techniques. Notice the dip in the 443 nm channel in the old N2Gen has been corrected with the new processing (viirs\_nrl2\_1, purple). Also notable is lately, the MODIS sensor has shown questionable performance in the blue channels (412 nm and 443 nm) therefore using it a validation point must be done with extreme caution.

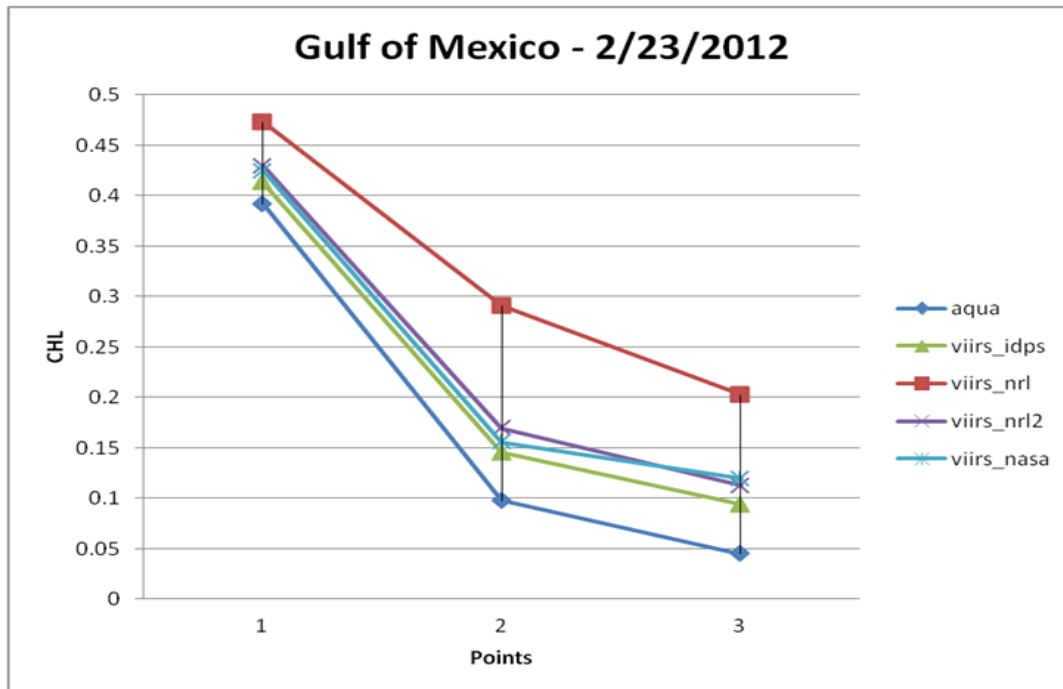


Figure 20 shows the effect of the N2Gen upgrade (viirs\_nrl2) on the chlorophyll products. The old N2Gen process returned a ‘dip’ in the 443nm radiance resulting in anomalously high chlorophyll retrievals shown by the red line (viirs\_nrl). Chlorophyll values for all three stations are shown transitioning from highly scattering coastal waters (point 1) to clear water conditions (point 3).

### 3.2.5 US East Coast – chlorophyll cruise

The comparison of algorithms between the Navy Environmental Data Records (EDRs) and IDPS ( $EDR_{govt}$  to  $EDR_{IDPS}$ ) processing has resulted in significant development and product evaluation. Figure 21 shows the chlorophyll EDR comparison of VIIRS data processed with NRL’s APS (*left*) and the future IDPS (*right*) compared to MODIS-Aqua (center). Chl-a values at co-located pixels are indicated in boxes for comparison; NRL = 4 mg/m<sup>3</sup> and future IDPS = 13 mg/m<sup>3</sup> with the legacy sensor, MODIS = 4.7mg/m<sup>3</sup>. The NRL processing seems reasonable as *in situ* data for MVCO suggests the range for the current year chlorophyll at the AOC location is 4-6 mg/m<sup>3</sup>, Figure 22. Additionally, Figure 23 provides a pixel by pixel comparison of the NRL VIIRS product with the future IDPS processing. This reveals additional development is needed by the IDPS for chl determinations.

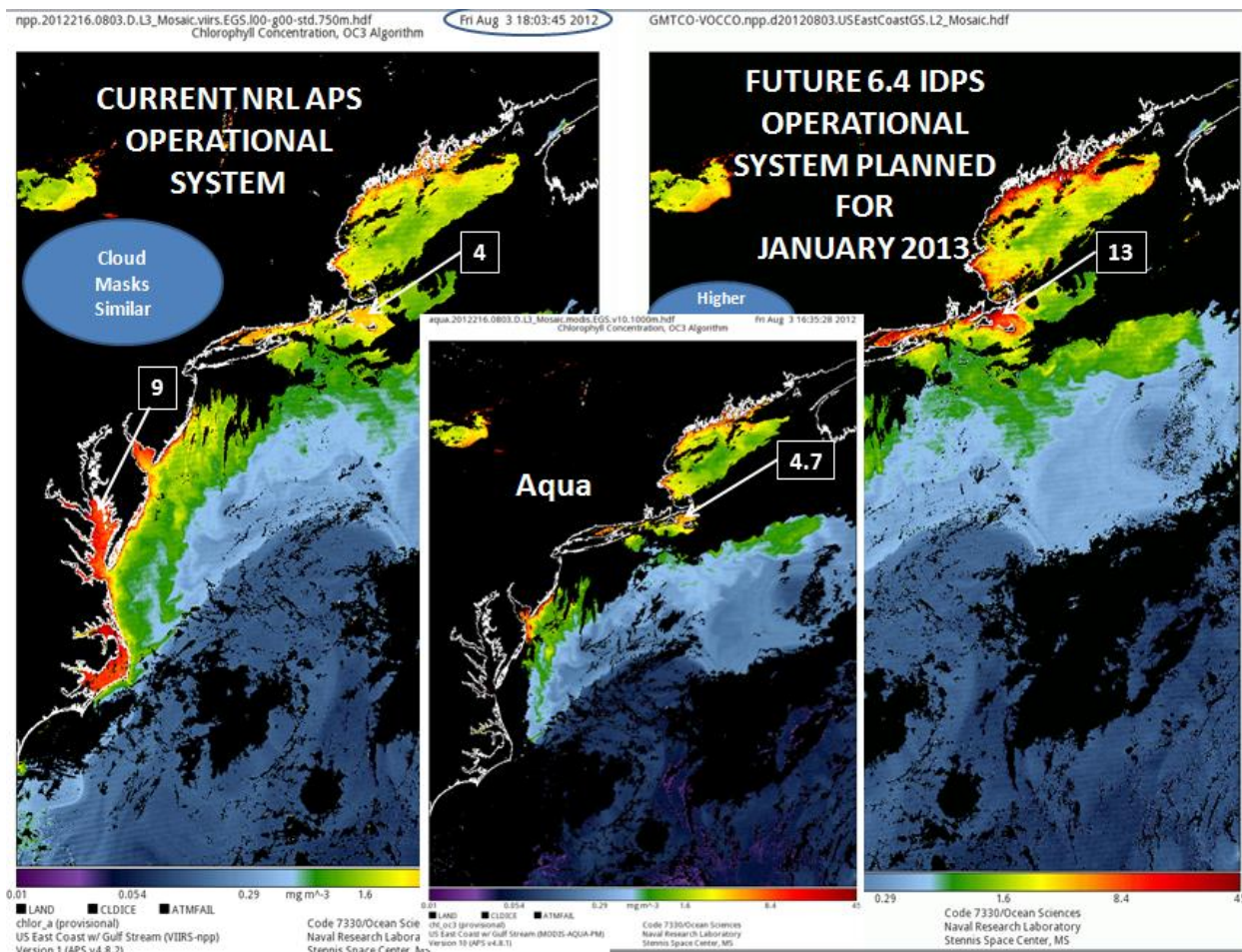


Figure 21 shows the chlorophyll EDR comparison of VIIRS data processed with NRL's APS (*left*) and the future IDPS (*right*) compared to MODIS-Aqua (center). Chl-a values at co-located pixels are indicated in boxes for comparison; NRL = 4 mg/m³ and future IDPS = 13 mg/m³ with the legacy sensor, MODIS = 4.7mg/m³.

**Time series observations** - Time series observations at MVCO were begun as part of previous programs and have been extended seamlessly with the start of this project. These include discrete samples, continuous in situ flow cytometry, and AERONET-OC based SeaPRISM measurements. These observations are currently being used in all other aspects of the project.

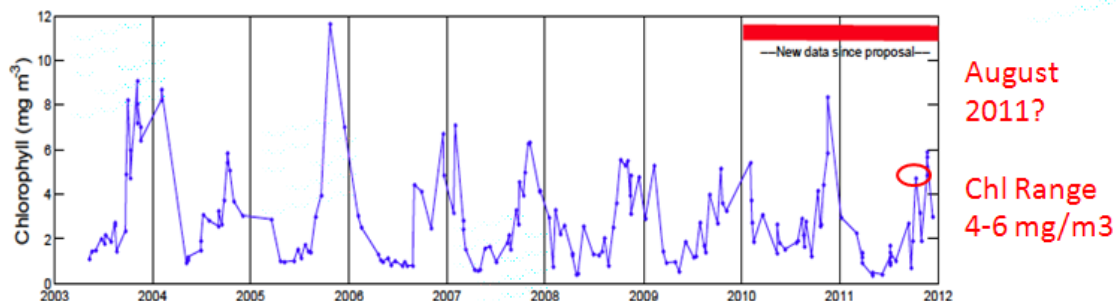


Figure 22 shows the chlorophyll range over time for the Martha's Vineyard AERONET-OC site.



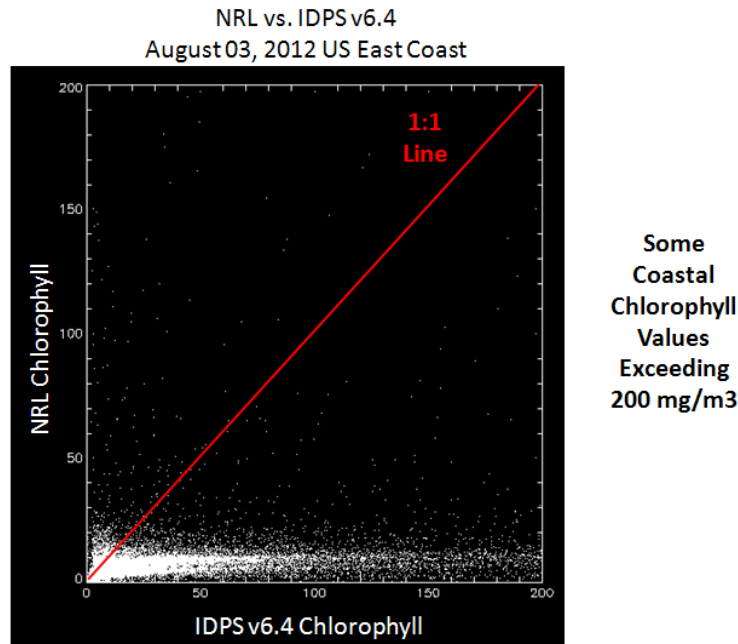


Figure 23 provides a pixel by pixel comparison of the NRL VIIRS product with the future IDPS processing. This reveals additional development is needed by the IDPS for chl determinations.

## 4 Operational Implementation

### 4.1 Operational Concept

The system will reside with NP3 at the Naval Oceanographic Office and automatically produce near real time (NRT) ocean color products from several satellites. Multiple real time satellite data streams of SDR (level 1) will be automatically processed, *via AOPS*, into Navy ocean optical products. Products produced by NAVOCEANO will support fleet operations and internal modeling efforts. Initial testing efforts have shown that approximately 1.25 hours are required to receive data from AFWA therefore an operational goal of approximately 2 hours to produce final products is reasonable.

*Note: NAVOCEANO will not be pulling EDR's for Ocean Color as they intend to use the Navy algorithms to support operations.*

### 4.2 Resource Requirements

The additional data storage requirements are being addressed within the NPOESS/ JPSS upgrades (A2).

### 4.3 Future Work

- Perform quarterly calibration and validation updates via the semi-automated “on-orbit vicarious calibration” technique. *This activity will also provide the ability to define the uncertainty of the inter-sensor products.*
- Prepare the NRT Geostationary Ocean Color Imager (GOCI) data stream for integration into operations.
- Improvements in sensor characterization and algorithm development will be addressed as new versions of AOPS are transitioned to NAVOCEANO.
- Improvements to the AOPS mosaicking capability
- Implement sharpening by using the VIIRS I-Bands
- Evaluate JPSS1, DWSS, Sentinel 3, GOCI-2 for operational products

## 5 Summary and Conclusions

The Navy’s initial assessment of the Visible Infrared Imager Radiometer Suite (VIIRS) on Suomi National Polar-orbiting Partnership (NPP) indicates ocean products are of high quality. Evaluations to date of the navy products and IDPS Environmental Data Records (EDR’s), indicates the sensor performs well as compared to current operational products derived from Moderate Resolution Imaging Spectroradiometer (MODIS) and *in situ* data.

Results indicate the VIIRS sensor should provide a continued data stream supporting operational products. The sensor appears reasonably well characterized and is generating quality ocean color products as compared to existing ocean sensing satellites. The VIIRS sensor appears to be capable of generating scientific research quality data in addition to meeting operational demands. Continued Cal/Val procedures are required to monitor and evaluate the sensor and product data stream for global trends. As the JPSS Cal/Val Team (NASA, NOAA, and NRL) begins to better characterize the sensor and monitor the trends of the sensor’s calibration tables, improvements to the generated ocean products are expected.

Ocean color algorithms for the navy are unique. NOAA and NASA products do not meet navy requirements and are unlikely to do so in the foreseeable future. Variations in ocean color processing, by NOAA’s Operational IDPS and the present NRL processing methods, based on L2gen (level 2 generator), have resulted in small differences in the EDR products. These issues are derived from software development differences such as atmospheric correction procedures and in-water algorithm differences. Table 2 provides a summary of the algorithm differences between the IDPS (L2Gen) and APS (N2Gen) processing. These differences impact things such as coastal retrievals, cloud masking and flagging. It is important to note that the described differences originate from software processing and are not inherent to the VIIRS sensor. Improved characterization of the sensor is evolving and is expected to enhance the scientific quality of all products.

Based on initial validation results, we recommend proceeding with operational processing of VIIRS sensor data using the Navy's Automated Processing System, which is based on L2gen for ocean color products. Although further analyses and improvements will be required, the products should provide an adequate follow-on and replacement to MODIS and MERIS data for Navy operations. The navy sees no reason that the VIIRS sensor should not provide scientific research quality data for new algorithm development and the capability to produce operational products to support the fleet as well as perform ecological monitoring in global ocean waters.

## 6 Technical References

Arnone, R.A, et al. 2012. *Monitoring Ocean Water Leaving Radiance for Inter-satellite Continuity*, Abstract ID: 12162, Ocean Sciences, Salt Lake City.

Bailey, Sean W., Stanford B. Hooker, David Antoine, Bryan A. Franz, and P. Jeremy Werdell. 2008. *Sources and assumptions for the vicarious calibration of ocean color satellite observations*, Applied Optics, v 47, p2035.

D'Alimonte, D., Zibordi, G. 2006. *Statistical assessment of radiometric measurements from autonomous systems*, IEEE Geosci. Remote Sens., v 44, p719.

D'Alimonte, D., Zibordi, G., Mélin, F. 2008. *A statistical method for generating cross-mission consistent normalized water leaving radiance*, IEEE Trans. Geosci. Remote Sens., v46, p 4075.

Fargion G. S. et al. 2012. *Real time Cal/Val with Satellite Validation NAVY Tool (SAVANT)*, Abstract ID: 11090, Ocean Science Mtg, Salt Lake City.

Franz, Bryan A., Sean W. Bailey, P. Jeremy Werdell, and Charles R. McClain. 2007. *Sensor-independent approach to the vicarious calibration of satellite ocean color radiometry*. Applied Optics, v 46, p5068.

Martinolich, Paul, 2012. *AOPS Users Guide v4.8*.

Mélin F, Zibordi G, Berthon J-F. 2007. *Assessment of satellite ocean color products at a coastal site*, Remote Sensing of Environment v 110, p 192.

Zibordi, Giuseppe, Brent Holben, Ily Slytsker, Davie Giules, Davide D' Alimonte, Fredreric Milin, Jean-Francois Berthon, Doug Vandemark, Hui Feng, Gregory Schuster, Bryan E. Fabbri, Seppt kaitala, and Jukka Seppala. 2009. *AERONET-OC: A Network for the Validation of Ocean Color Primary Products*, Journal of Atmospheric and Oceanic Technology v 26, p1634.



## 7 List of Acronyms

Advanced Very High Resolution Radiometer (AVHRR)  
Aerosol Optical Thickness (AOT)  
Aerosol Robotic Network (AERONET)  
Aerosol Robotic Network- Ocean Color (AERONET-OC)  
Air Force Weather Agency (AFWA)  
Anti-Submarine Warfare (ASW)  
Automated Optical Processing System (AOPS)  
Calibration and validation (Cal/val)  
Colored dissolved organic matter (CDOM)  
Comprehensive Large Array-data Stewardship System  
Environmental Data Records (EDRs)  
Expeditionary Warfare (EXW)  
Geostationary Ocean Color Imager (GOCI)  
Global Imager (GLI)  
Government Resource for Algorithm Verification, Independent Testing and Evaluation (GRAVITE)  
Graphical user interface (GUI)  
Hierarchical Data Format (HDF)  
Integrated Data Processing System (IDPS)  
Japanese Ocean Color and Temperature Sensor (OCTS)  
Joint Polar Orbiting System (JPSS)  
Level 2 generator (L2Gen)  
Look up table (LUT)  
Marine Optical Buoy (MOBY)  
Medium Resolution Imaging Spectrometer (MERIS)  
Meteorology and Oceanography (METOC)  
Mine Warfare (MIW)  
Moderate Resolution Imaging Spectrometers (MODIS, on Terra and Aqua)  
National Aeronautic and Space Administration (NASA)  
National Center for Supercomputer Applications (NCSA)  
National Oceanographic and Atmospheric Administration (NOAA)  
National Polar-orbiting Observation Environmental Satellite System (NPOESS)  
Naval Oceanographic Office (NAVOCEANO)  
Naval Research Laboratory (NRL)  
Naval Special Warfare (NSW)  
Near infrared (NIR)  
Near real time (NRT)  
Normalized water leaving radiance (nLw)  
Ocean Biology Processing Group (OBPG)  
Ocean Colour Monitor (OCM)  
Polarization Detection Environmental Radiometer (POLDER)  
Quasi-Analytical Algorithm (QAA)  
SAVANT - Satellite Validation Navy Tool  
Sea-viewing Wide Field-of-view Sensor (SeaWiFS)  
Space and Naval Warfare Systems Command (SPAWAR)  
Suomi National Polar-orbiting Partnership (NPP)  
Suspended particulate matter (SPM)  
Total radiance signal at the top of the atmosphere (TOA)  
Validation Test Report (VTR)  
Visible Infrared Imager Radiometer Suite (VIIRS)

## 8 Appendix

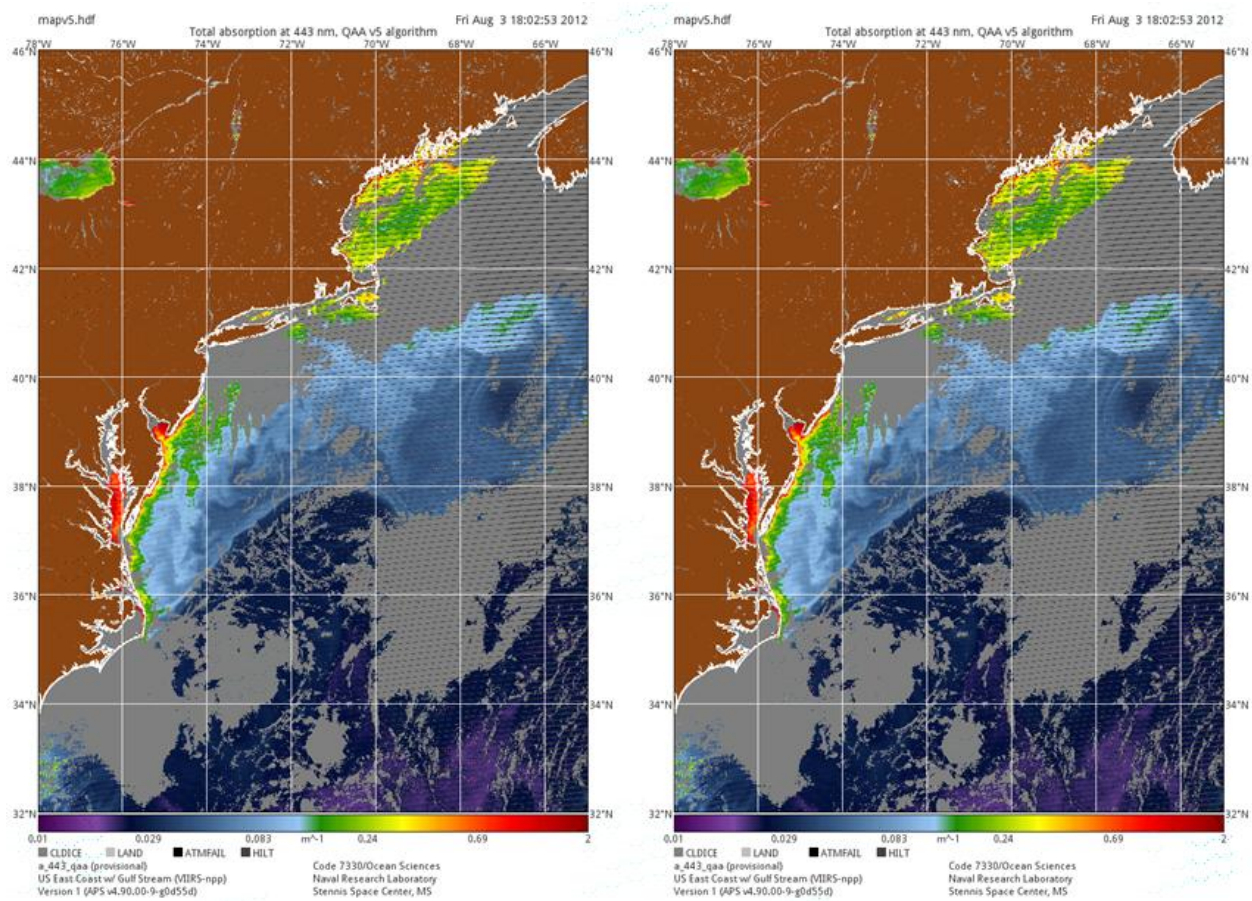
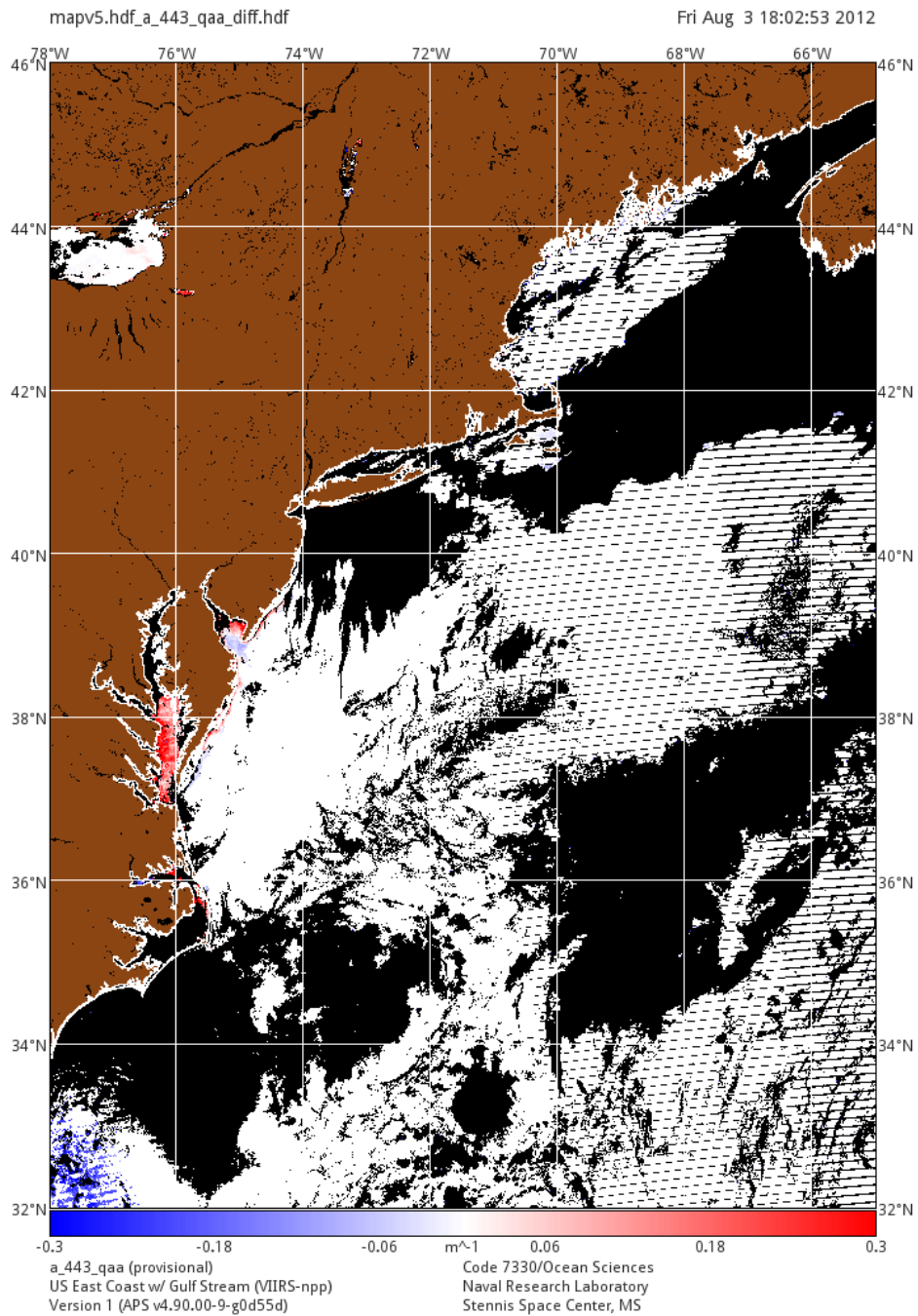


Figure A 1 shows the version 5 QAA (left) and the version 6 QAA (right) upgrade of the total absorption product at 443nm.



**Figure A 2 shows the image difference between the QAA version 5 and version 6 443 nm total absorption products. The enhancements are seen in the coastal waters.**



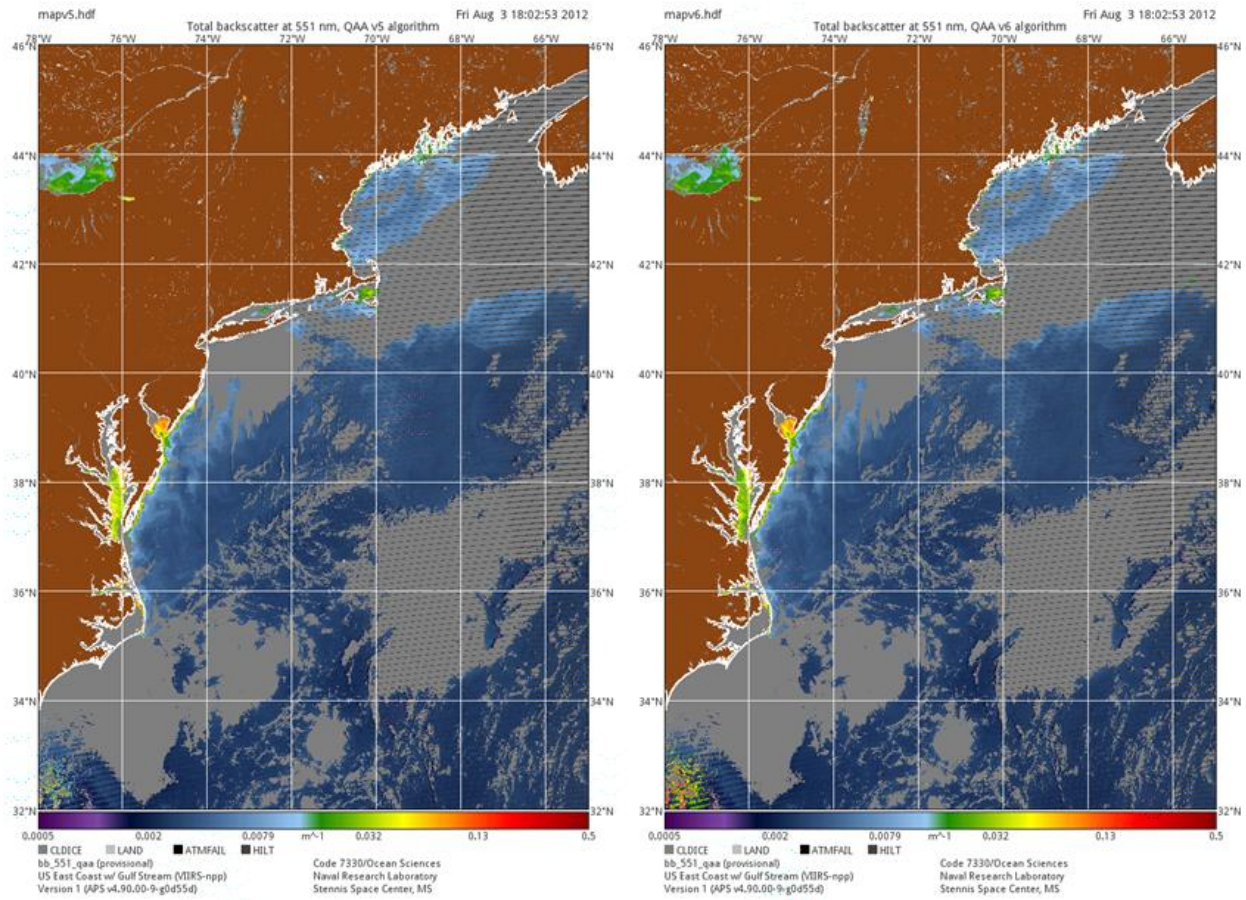
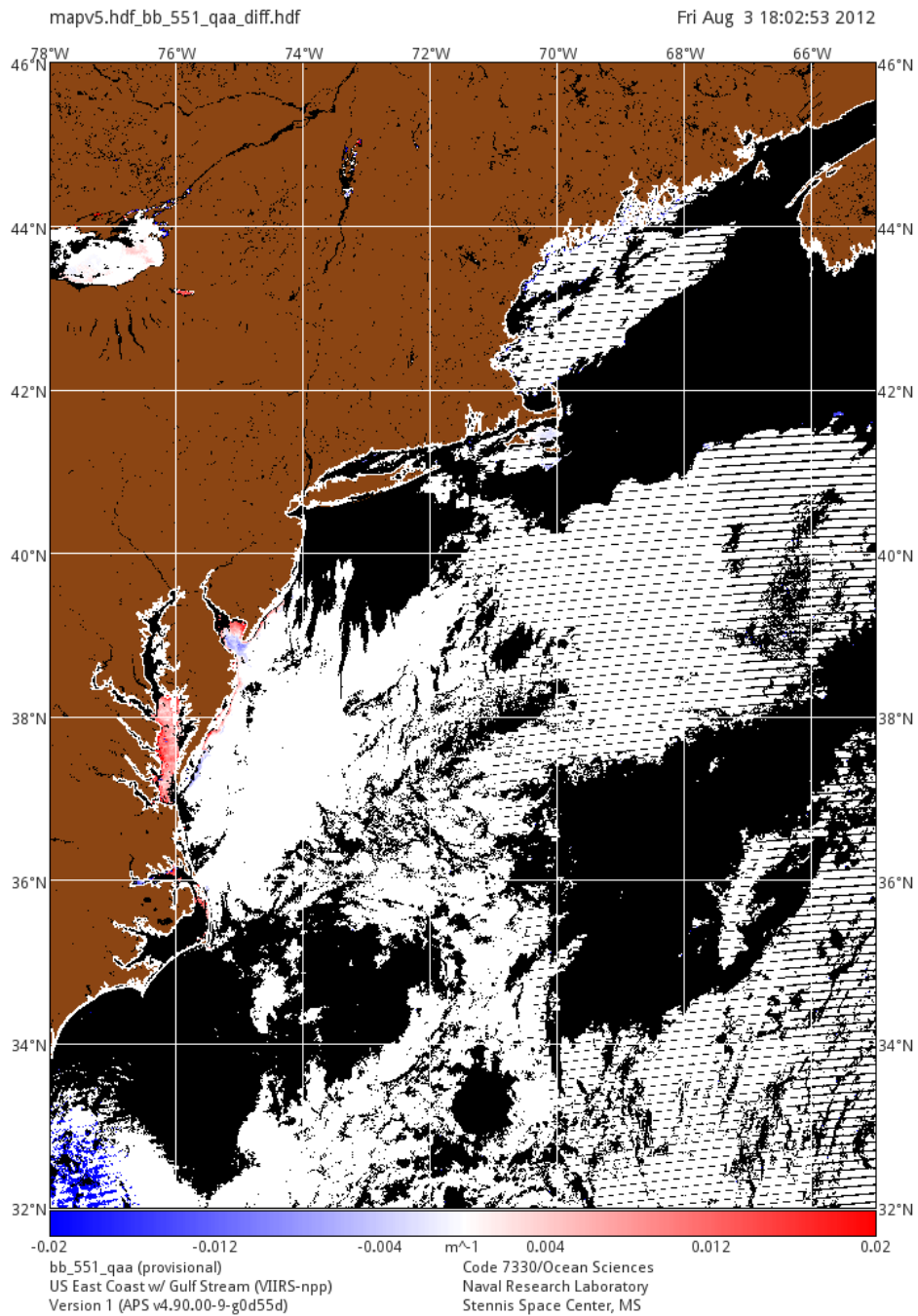


Figure A 3 shows the version 5 QAA (left) and the version 6 QAA (right) upgrade of the backscatter product at 551nm.



**Figure A 4 shows the image difference between the QAA version 5 and version 6 551 nm backscatter products. The enhancements are seen in the coastal waters.**